DAHLGREN DIVISION
NAVAL SURFACE WARFARE CENTER
Panama City, Florida 32407-7001

CSS/TR-01/09

SHAPING THE FUTURE OF NAVAL WARFARE WITH UNMANNED SYSTEMS

DELBERT C. SUMMEY, RAFAEL R. RODRÍGUEZ, DAVID P. DEMARTINO, HELMUT H. PORTMANN JR., AND ELAN MORITZ

SCIENCE, TECHNOLOGY, ANALYSIS AND SPECIAL OPERATIONS DEPARTMENT

COASTAL SYSTEMS STATION

JULY 2001

REPORT DOCUMENTATION PAGE

Form Approved
OMB NO. 0704-0188

1. AGENCY USE ONLY (*Leave Blank*)

2. REPORT DATE
July 2001

3. REPORT TYPE AND DATES COVERED

4. TITLE AND SUBTITLE
SHAPING THE FUTURE OF NAVAL WARFARE WITH UNMANNED SYSTEMS

5. FUNDING NUMBERS

6. AUTHOR(S)
Delbert C. Summey, Rafael R. Rodríguez, David P. DeMartino, Helmut H. Portmann Jr., and Elan Moritz

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Attn: Code R10
Commander
Coastal Systems Station, Dahlgren Division
Naval Surface Warfare Center
6703 W. Highway 98
Panama City, FL 32407-7001

8. PERFORMING ORGANIZATION REPORT NUMBER
CSS/TR-01/09

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSORING / MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES
The views, opinions and/or findings contained in this report are those of the author(s) and should not be construed as an official Department of the Navy position, policy or decision, unless so designated by other documentation.

12 a. DISTRIBUTION / AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

12 b. DISTRIBUTION CODE
A

13. ABSTRACT (Maximum 200 words)
This report presents the findings of a study conducted for the purpose of understanding how unmanned systems can enhance the readiness of U.S. Naval forces. The document presents reasons why unmanned systems should be adopted by the Navy, and makes the case for coordinating the development of unmanned systems technology across all major warfare areas. Following the systems engineering methodology, the study team identified Navy capabilities that unmanned systems can support, and defined functional elements that unmanned systems must have in order to fulfill the selected capabilities. The analysis showed that a limited number of payloads installed on four types of modular unmanned platforms is sufficient to support a wide range of major capabilities. The report also describes a concept for transportation and deployment of unmanned systems based on the use of standard shipping containers. This approach minimizes the impact of unmanned components on Fleet combatants while allowing unmanned platforms to perform assigned tasks in a timely manner.

14. SUBJECT TERMS
Unmanned Systems, Unmanned Vehicles, Naval Force, Standard Warfare Systems, Naval Lift

15. NUMBER OF PAGES
116

16. PRICE CODE

17. SECURITY CLASSIFICATION OR REPORT	18. SECURITY CLASSIFICATION ON THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	**UNCLASSIFIED**	**UNCLASSIFIED**	**UL**

NSN 7540-01-280-5500

Standard Form 298 (Rev.2-89)
Prescribed by ANSI std. Z39-18
298-102

FOREWORD

Coastal Systems Station (CSS) has been involved for many years in the development of unmanned systems technology for the Navy. This technology has matured to a point of readiness for widespread introduction into Fleet systems. This fact is made evident by programs like the Pioneer Unmanned Air Vehicle, the Remote Minehunting System, the Tactical Control System, and the Long-Term Mine Reconnaissance System. These programs have delivered, or will soon introduce unmanned systems into the Fleet.

Because unmanned systems technology is relatively new, current programs are focused on unique systems optimized to particular applications. CSS believes that achieving the full potential of this technology requires a comprehensive view of the role of unmanned systems in all warfare areas to ensure that the systems support multiple uses, and can be procured in sufficient numbers to be effective. With this view, CSS began a study in Fiscal Year 2000 using internal funds. The effort was led by the Science, Technology, Analysis, and Special Operations Department (Code R), with the goal of developing a concept for the role and use of unmanned systems in the Navy. Such a concept will allow the Navy research and development activities, industry, and academia to focus on providing solutions to the critical technology problems that will enable unmanned systems to join the Fleet.

This report presents the outcome of the study. The concept development team was composed of Team Leader David P. DeMartino, Code R06, David E. Everhart, Code R05, Dr. John Lathrop, Code R20, Dr. Elan Moritz, Code R0X, Walt Rankin, Code A06, and Rafael R. Rodríguez, Code R11. The team developed a concept for the development and operation of unmanned systems with Fleet combatants. The concept is a comprehensive view of the role that unmanned systems can play to support Navy missions in the future.

The authors wish to acknowledge the support of the Warfare Analysis Division (Code R30), including Mr. Paul Pettofrezzo, Mr. Terrence Dye, and Mr. Curtis McVey. Their ideas and constructive observations contributed to improving the unmanned systems concept presented here.

The mention or use of specific unmanned vehicle examples or images from commercial sources in this report does not represent endorsement of any kind by the authors, CSS, or the U.S. Government.

Approved by:

Martin A. Kidd

Martin A. Kidd, Acting Head
Science, Technology, Analysis and Special
Operations Department

CONTENTS

CONTENTS (CONTINUED)

ILLUSTRATIONS

ILLUSTRATIONS (CONTINUED)

TABLES

GLOSSARY

Acoustics	Characterization of a device based on acoustic energy signals
ACTD	Advanced Concept Technology Demonstration
ALV	Autonomous Land Vehicle
AOI	Area of interest
ARG	Amphibious Ready Group
AUV	Autonomous Undersea Vehicle
BDA	Battle Damage Assessment
C^2	Command and Control
C^3	Command, Control, and Communications
CAPS	Coastal Area Protection System
CBR	Chemical, Bacteriological, Radiation
CCITT	*Comité Consultatif International Téléphonique et Télégraphique*
CGA	Color Graphics Adapter
COBRA	Coastal Battlefield Reconnaissance and Analysis
Comms	Communications
CONUS	Continental United States
CSS	Coastal Systems Station
CVBG	Carrier Battle Group
DARPA	Defense Advanced Research Projects Agency
DMR	Digital Modular Radio
EO	Electro-Optical
EOD	Explosive Ordnance Disposal
FNC	Future Naval Capabilities
GATORS	Ground/Air Telerobotic Systems
I/O	Input/Output
IR	Infra-red
ISO	International Standards Organization
ITU	Same as CCITT
LCAC	Landing Craft, Air Cushion Vehicle
LMRS	Long-Term Mine Reconnaissance and Avoidance System

GLOSSARY (CONTINUED)

Magnetics	Characterization of a device based on magnetic energy signals
MCM	Mine Countermeasures
mmW	Millimeter Wave
MPF	Maritime Prepositioned Force
Nav	Navigation
NLW	Non-Lethal Weapon
NMRS	Near-Term Mine Reconnaissance System
NRAC	National Research Advisory Committee
OHB	Hydrographic, bathymetric, and oceanographic
ONR	Office of Naval Research
OPTEMPO	Operational Tempo
P^3I	Pre-planned Product Improvement
PC	Personal computer
POW	Prisoner of War
Recon	Reconnaissance
RF	Radio Frequency
RMS	Remote Minehunting System
ROC	Required Operational Capability
ROV	Remotely-operated vehicles
RSTA	Reconnaissance, Surveillance, and Target Acquisition
R-T	Reconnaissance-Targeting
SAHRV	Surveillance and Hydrographic Reconnaissance Vehicle
SBx	Operational sea-base
SE	Systems Engineering
SLT	Solid Logic Technology
SMS	Standard Modular System
SOMSS	Submarine Offboard Mine Search System
SQL	Structured Query Language

GLOSSARY (CONTINUED)

SRS	Standardized Robotic System
TCS	Tactical Control System
TEU	Twenty-foot equivalent units
TMAP	Teleoperated Mobile Anti-Armor Platform
TOV	Teleoperated Vehicle
UAN	Unmanned Air Node
UAV	Unmanned Air Vehicle
UCAV	Unmanned Combat Aerial Vehicle
UGN	Unmanned Ground Node
UGV	Unmanned Ground Vehicle
USN	Unmanned Surface Node
USV	Unmanned Surface Vehicle
UUN	Unmanned Underwater Node
UUV	Unmanned Underwater Vehicle
UXO	Unexploded Ordnance
VTUAV	Vertical Takeoff UAV
WARM	Wartime Reserve Mode

EXECUTIVE SUMMARY

Naval Surface Warfare Center, Dahlgren Division's Coastal Systems Station initiated a special study in 2000 to examine the potential of unmanned systems to augment U.S. Naval Forces in the future. This report documents findings of this study, that there is a coherent overall framework for the development, deployment, and operation of unmanned systems on a broad basis across the major naval mission areas. This framework advocates standardized unmanned systems for affordability in large numbers, lift concepts to get them into theater with minimal impact to combatant ships, and concepts for operation and sustainment.

Development of unmanned systems in the Department of Defense has proceeded predominantly from the "bottom up", with unique designs for specific missions. Most unmanned aerial, undersea, surface, and ground vehicles today represent custom designs that grew out of individual development efforts focused on specific performance objectives. The result, as illustrated in Figure E-1, is a large number of unique vehicle designs with little standardization or commonality. Although master plans and coordinating program offices are now established for all but unmanned surface vehicles, the emergent system approaches largely address independent non-interacting unmanned systems and tend to remain segregated into specific platform "stovepipes". Large numbers of unmanned systems will eventually be required if they are to impact future warfare. Standardization and modularity across all unmanned systems will be the key to affordability.

This study adopted a systems engineering methodology to conduct a requirements analysis of a large number of naval capabilities. A timeframe around 2030 was selected with projected naval combatant force levels based on current mission and shipbuilding planning forecasts. A foundational premise of the work was that unmanned systems would not replace, but would augment manned combatant platforms. A set of top-level requirements that unmanned systems must support was identified. These requirements were functionally decomposed and allocated to a set of 39 types of general payload modules that could be carried on four types of standard unmanned system platforms. A key finding of this report is that a limited number of general modules can support a broad range of naval missions.

The study examined a number of component design approaches and identified modularity as another key to success in unmanned systems design, development, and operational deployment. An important conclusion and recommendation is to apply modularity-oriented design across unmanned systems from the top down. Engineering constraints and physics will impose limits on what can be accomplished, but these should not drive the overall systems engineering approach; rather they should be applied within the context of the larger approach.

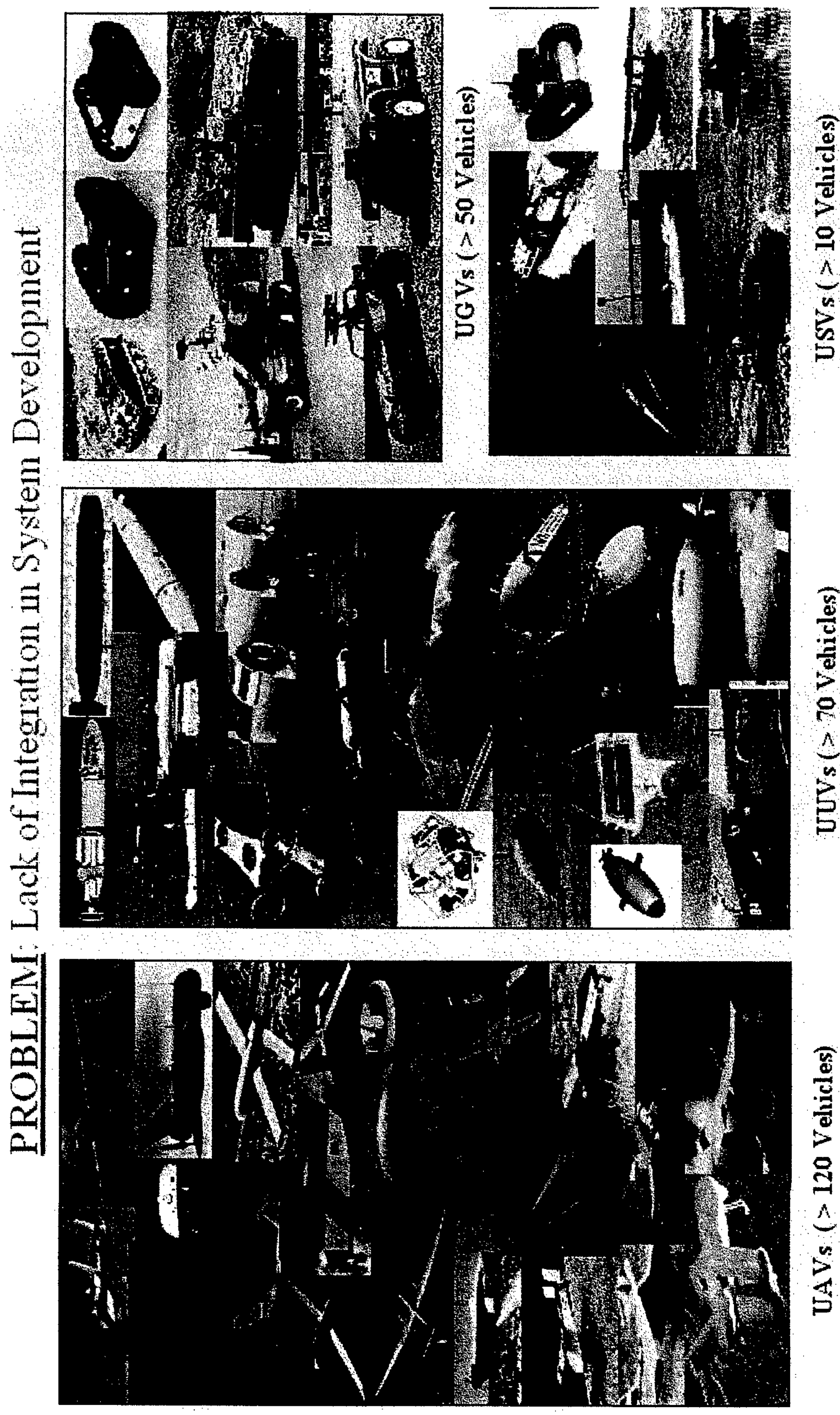


FIGURE E-1. UNMANNED SYSTEMS TECHNOLOGY – CIRCA 2001

Having identified a standard set of unmanned systems that could be equipped with a limited number of standard payload modules, the next issue to address was how to get them into theater.

Lift, how large numbers of unmanned systems are brought into theater, and are deployed and sustained represent very significant challenges. Lift will be a major driver in how future unmanned systems evolve to fit within warfighting doctrine. Almost every significant change in the Navy has resulted in modification to ships. It is important to address now if and how future ships will be adapted to operate with unmanned systems. There are a number of potential directions to take including new military sealift vessels, new combatant designs, and employment of commercial vessels. The study revealed that application of commercial International Standards Organization (ISO) shipping container-based launch and recovery systems will afford the flexibility and economy of scales that will be required for affordable acquisition and realistically achievable deployment. These ISO container-launched systems can be employed either "out of container" in large numbers or organically onboard combatants in smaller numbers.

Combining the concepts for standardized unmanned systems with modular payloads and the concepts of standardized containerization for lift, a new, more orderly view of a future system of unmanned systems develops, as illustrated in Figure E-2. The focus of this approach is oriented more on affordability and deployability on a large scale as opposed to niche performance of individual, unique systems. We believe that this is the key to development of a sustainable Naval Augmentation option making valuable and economic use of unmanned systems in the future.

Deployment of large numbers of unmanned systems in warfighting scenarios will also require a dramatic evolution of operation and control concepts. Today we are already thinking in terms of controlling multiple vehicles of one type (e.g. three or six unmanned aerial vehicles) from a common control station. With large numbers of all types of unmanned systems the general control strategy will have to take on an entirely new dimension wherein the theater commanders and on-scene combatant personnel become the "users" of the products and services provided by the unmanned systems, without the need to worry about the operation and control of the specific unmanned systems themselves. An illustrative example is the delivery of imagery and other intelligence products produced by national assets in real-time for consumption by theater commanders. The theater commander does not have to worry about the operation or control of the national assets themselves, he only requests and receives a product or service. In fact, the deployment, operation, and control of the national assets themselves may involve a broad spectrum of personnel distributed all over the globe.

DOD is currently investing over $600M per year on unmanned aerial vehicles, probably upwards of $1B per year when one factors in support and training. Meanwhile, as the roles and significance of unmanned undersea, surface, and ground vehicles continue to grow to similar levels, it is reasonable to expect that the total U.S. defense budget outlay for unmanned systems will grow as well. National investment of this magnitude with the concomitant reliance on unmanned systems to support our troops predicates that an orderly and systematic engineering approach be instituted to mature these technologies to the significant and crucial role that awaits them in future combat.

The underlying conclusion of this report is based on the systems engineering methodology, the close examination of required capabilities statements, and the functional mission decomposition with attendant module allocations. The conclusion is that naval forces stand to dramatically benefit from adoption of a comprehensive modular, standardized unmanned systems design, development, and deployment framework.

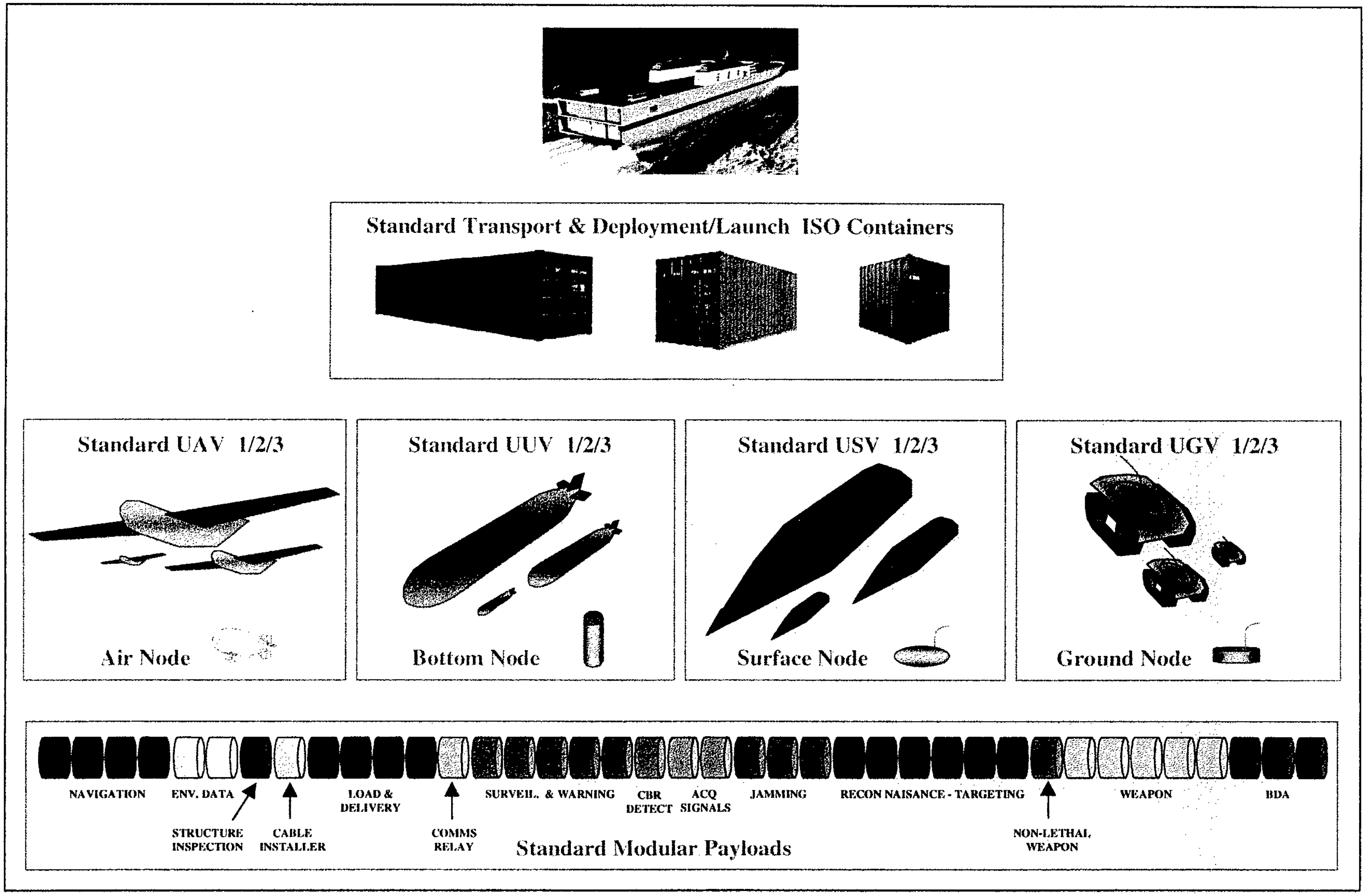


FIGURE E-2. CONCEPT FOR UNMANNED SYSTEMS – CIRCA 2030

SECTION 1.0 INTRODUCTION

> For all the military planning that went into the preparations for World War II, as of 1939 none of the major powers had decided to pursue the weapon that would ultimately prove decisive, the atomic bomb.
>
> James Fallows, *National Defense*

1.1 PURPOSE

James Fallows, in *National Defense*, brought attention to several truths regarding history and the future of military combat.[1] His main theme amplified the thought captured in the quote above: "the common sense approach to defense is to recognize that the future is uncertain, and to develop forces and strategies that give us the greatest possible capacity to adapt to whatever the future brings." The purpose of this report is to document the process and results of the Unmanned Systems Thrust initiated at the Coastal Systems Station (CSS) in May, 2000, and to serve as the conceptual foundation for follow-on efforts establishing a coherent overall framework for the development, deployment, and use of unmanned systems by U.S. Naval Forces and the Department of the Navy. The objective of the effort is to provide U.S. Naval Forces with the greatest capacity to adapt to and meet an uncertain future.

We recognize that considerable effort has been exercised to date with goals of introducing, and adapting to military use, a variety of unmanned vehicles. For the most part, the efforts to date have focused on individual vehicle systems. Assessing a variety of needs, missions, requirements, systems, technologies, and technology opportunities can contribute to an integrated balanced perspective. We have undertaken this assessment to facilitate unmanned systems development and integration into Navy concepts of operations. This report recommends the initial steps towards what we expect to be a generational change; it postulates a coherent framework for solid design principles and significant specific system designs. These initial steps and framework will provide the basis for the Joint Services and the defense industrial community to capitalize on the benefits arising from common design principles, standards, and a coherent approach. A few of the practical benefits to be realized are:

- Dollar savings in development, manufacture, deployment, and operational use
- Significant manpower savings realized in reduced costs
- Reduced casualties

The material presented in this report, in short, is a blueprint for the coherent development of unmanned systems as ready-to-fight naval readiness augmentation fleet components enabling the Fleet to engage anywhere, anytime.

1.2 REPORT ORGANIZATION

Section 2.0 articulates the case for unmanned systems within DOD. It is focused on that portion of the audience that remains skeptical regarding widespread use of unmanned systems within the military.

Section 3.0 provides a background survey of the history of unmanned systems development within DOD, and provides additional context for the state of unmanned systems today.

Section 4.0 outlines the Unmanned Systems Concept Development Study that produced the foundation for the overall framework for unmanned systems development espoused in this report.

Section 5.0 addresses the issue of lift, and presents a concept for standardized containerization that serves as the foundation for development of realizable deployment schemes for large numbers of unmanned systems.

Section 6.0 presents a summary of the authors' observations and conclusions.

Section 7.0 provides references.

SECTION 2.0 THE CASE FOR UNMANNED SYSTEMS

2.1 OVERVIEW

Unmanned systems are stand-alone systems that can execute missions and tasks without direct physical manned presence and/or control. There are many types of unmanned systems with varying levels of remote control, ranging from continuous remote telepresence control to fully autonomous unmanned systems. The case for unmanned systems will be established by first examining the motivation for broad application of unmanned systems to naval missions. Next, the argument is extended to the need for standardization and modularity in unmanned systems to make them affordable and deployable in very large numbers. Finally, the case for unmanned systems is placed into the context of a larger picture, where it is shown that military application of unmanned systems and standards is only a small (and natural) extension of a much larger technological trend in automation, standardization, and modularization that has been evolving and changing our lives since the dawn of the Industrial Revolution.

2.2 MOTIVATION FOR CONSIDERATION OF UNMANNED SYSTEMS

The confluence of several factors that are already shaping the "Next Navy" and the "Navy After Next" provides a strong motivation for the broad application of unmanned systems as a continuum across the spectrum of naval missions. We will begin the discussion of the motivation for consideration of unmanned systems by examining the need to augment naval forces to help mitigate steady declines in ship numbers and manpower. Next, the argument is strengthened by technical reasoning that shows how unmanned systems will improve warfighting capabilities and political reasoning for how unmanned systems will make warfighting easier in today's news-absorbed world. Finally, economic reasoning is offered to show how unmanned systems in large numbers can be applied affordably by taking advantage of the economies of scale.

2.2.1 Decreasing Ships and Manpower

The defining element of the post-Cold War era is the transition from a bi-polar, nuclear arms dominated environment toward a multi-polar, conventional-arms security environment. We presently find ourselves in a transitional mono-polar environment dominated by a single superpower (United States). Associated with this transition to a multi-polar system are changes in defense budget allocations, and the significant change from draft-based 'conscript' armed services to an all-volunteer force.

The defense policy has evolved from a perceived "Enemies at the Gate", spare-no-expense approach, to a traditional intra-war mind-set that, at times, prescribes total budget caps at challenging levels, and is always extremely budget sensitive. The defense budget sensitivity has been demonstrated in the past decade through significant reductions in manpower, infrastructure, R&D investments, domestic and overseas bases, and a myriad of program

reductions. These reductions are reflected in the dramatic reduction in the number of naval combatants since WW II.

At the macro level U.S. Naval combatant forces have fluctuated with major wars.[2] Figure 2-1 shows the U.S. Naval combatant counts from 1917 on. Note the large number of vessels during WWII.

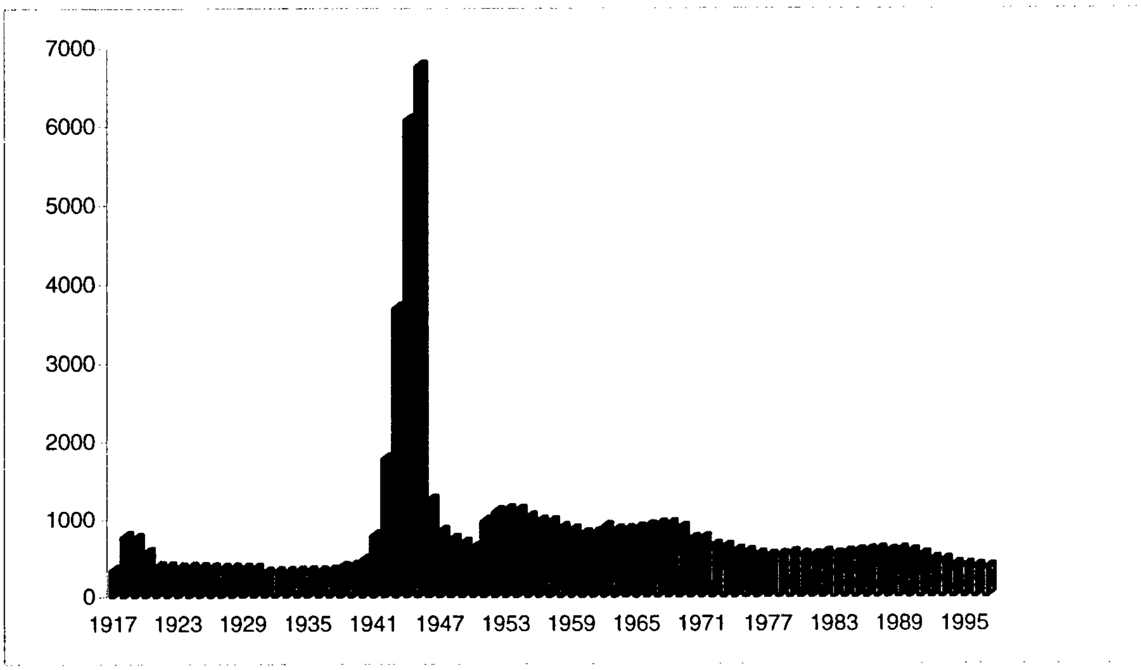


FIGURE 2-1. U.S. NAVAL COMBATANTS FROM 1917 TO 2000

Figure 2-2 provides more details of recent ship counts. The Navy Today snapshot of April 20, 2001 lists 316 ships in the Navy, an active duty end-strength of 370,538, and a reserve end-strength of 86,058.

Clearly, the numbers of combatants in service are declining. At the same time, the pace of military operations or "operational tempo" (OPTEMPO) has increased dramatically with numerous humanitarian, peacekeeping, and nation-building operations all around the globe. In many cases, our amphibious ready groups (ARGs) are conducting what are called split-ARG operations where what is typically a three-combatant ARG operates over a vast ocean extent or even over several oceans, with one ship in one ocean, and other ships of the ARG in another ocean. This pace of operations has been recognized as quite demanding.

Carrier battle groups (CVBGs) operate at high readiness all around the world with similar OPTEMPO pressures. These high OPTEMPO rates and demanding operations have resulted in severe manpower challenges and, at times, serious manpower shortfalls.

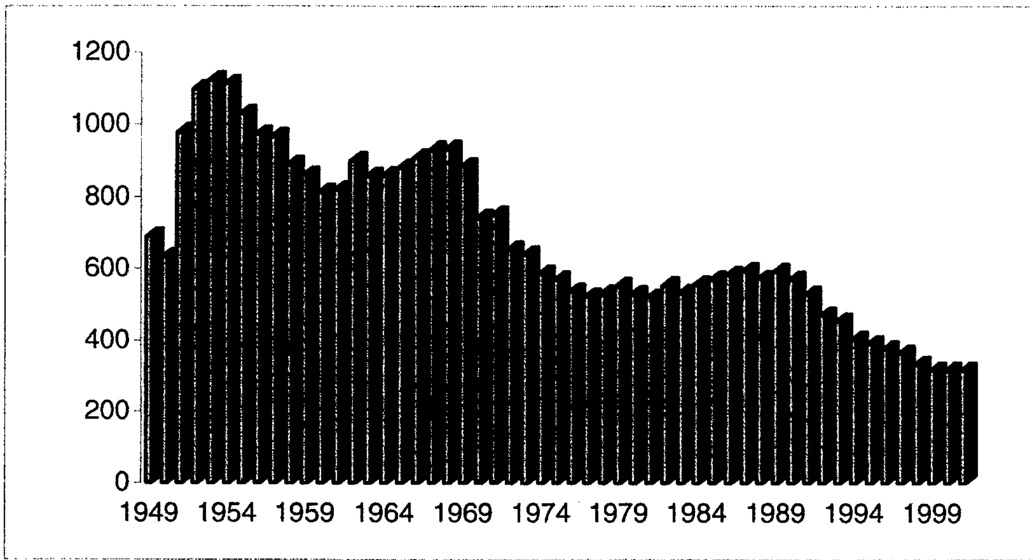


FIGURE 2-2. DETAILS OF RECENT U.S. NAVY COMBATANT LEVELS

In view of a combination of policy, budget, and manpower difficulties, the Navy has recognized the need to design ships that require many fewer sailors to operate. In fact, the target staffing for the new design DD-21 class destroyers call for overall manning levels of 95 sailors and officers. By comparison, earlier destroyers have four times or more sailors and officers. The trend for the future is clearly toward fewer more expensive ships, within a context of increasingly constrained manpower resources. Figure 2-3 shows the manning levels of destroyers in recent times.

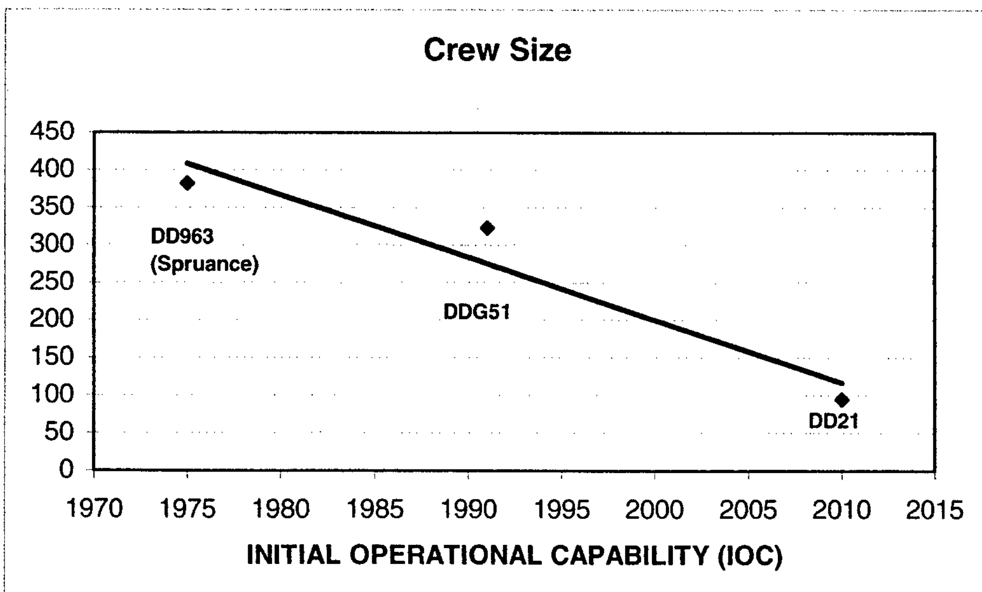


FIGURE 2-3. DESTROYER CREW SIZE TRENDS

The FY 2000 Annual Report to Congress[3] stated: "In 1999, both the Army and Air Force fell short of their recruiting goals. Although the Navy and Marine Corps attained their goals, the cost in both dollars and effort was greater than it has been in the past. Recruiting shortfalls over time will adversely impact the readiness of the Services by limiting the ability to properly man squads and crews." The statutory Navy Department statement was:

> "The Marine Corps has met or exceeded its accession goals since June 1995. To maintain their successful recruiting stance in the future, the Marine Corps is restructuring the locations of its recruiters to more effectively solicit target populations. The Navy met its accession mission and end–strength requirements in FY 1999. Additionally, the Navy has reduced the 18,000 at–sea billet gap identified last year by 35 percent in 1999. Several initiatives contributed to this success, including increasing the recruiting force by over 30 percent; expanding the number of recruiting stations; increasing financial and educational incentives, such as the Navy College Fund; and refocusing their advertising strategy. The recruiting environment however, remains challenging. While the Navy met its accession requirements for FY 1999, it was not able to improve its recruiting posture entering 2000 as the Delayed Entry Program numbers remain lower than desired."

Regarding officer retention, the report stated: "During the past few years, declining fleet size masked the adverse impact of reduced accessions and lower retention." The language of the report clearly points to a troubling trend of shortfalls in filling Navy sea billets and Marine ground and air specialists. These recruiting and retention factors must be taken into consideration as the "Navy After Next" is being designed.

Unmanned systems offer an opportunity to mitigate these platform and manning shortfalls if they can be applied across the broad spectrum of naval missions and in sufficiently large numbers to make a warfighting difference.

2.2.2 Technical Reasoning

Many factors argue for the increased use of unmanned systems beyond the obvious advantage of reducing the risk of loss of U.S. service persons lives. The removal of humans from a vehicle removes the need for significant life support and protective features that have to be incorporated in manned vehicles and thus offers significant opportunity to increase mission capabilities and performance. A recent USAF study listed the considerations shown in Table 2-1 as part of a major unmanned air vehicle (UAV) study.[4]

TABLE 2-1. MAJOR ATTRIBUTES OF UAVS LISTED IN *UAV – TECHNOLOGIES AND COMBAT OPERATIONS*

ATTRIBUTE	FUNCTIONAL IMPACTS
Endurance/Presence - Persistent Surveillance	• Continuous Deterrence • Reduced Aircraft-per-Orbit Quantities Required • Reduced Crew Fatigue • Broad, Distributed Communications Relay • Self-Deployable From Continental United States (CONUS); Can Operate From CONUS • Reduced Cost of Coverage
Unmanned - Perform High Attrition Combat Tasks	• Carry Weapons (With Fratricidal Possibilities) • Operate in Contaminated Environments • Operate in Provocative Role, Drawing Fire • Potentially Simpler: Reduced Cost • Reduced Crew Fatigue Problem • Less Thorough Safety Testing Required • Potential Kamikaze Employment • Reduced Cost of Coverage • Less Reasoning Power Than Manned Aircraft • Greater Need For Command and Control Tether • Crew-Saves (Aircraft and Mission) More Difficult, Less Likely
Automated - Simpler, Less Costly Training	• No Crew Safety Testing • Control Interface Simpler Than Remotely Piloted Aircraft • Less Stressing to Crews • Reduced Cost of Coverage • Reduced Physical Requirements for Operators • Crew-Saves (Aircraft and Mission) More Difficult, Less Likely
Distributed & Proliferated	• Quick Response Within Zone of Coverage • Behind-the-Lines Operation • Combined Attack (Multiple Weapons) • Broad Area Coverage With Multiple Sensors • Persistent Surveillance • Reduced System Vulnerability
High Altitude Operation - Survivable	• Performance Enhancements • Broad Area Coverage • Reduced Cost of Coverage • Better Viewing Angle For Enhanced Target Doppler, RCS • Advantageous Geometry For TBM Intercept
Low Altitude - Loss Affordable Operation	• Operate at Short Range (Smaller Weapons, Jammers, Radars)

The summary volume of the USAF's major study *AF2025: New World Vistas* presents several compelling discussions regarding increased survivability of unmanned combat air vehicles (UCAVs).[5] The specific reasoning for increased survivability is that it is possible and desirable to increase UCAV maneuverability beyond human pilots' tolerances. Acceleration limits for manned craft are, typically, +9 g or 10 g and -3 g, while UCAVs can be designed to accelerate well beyond that. Technically, most anti-aircraft missiles are designed to be about three times as acceleration capable over target aircraft. According to the study, UCAVs "with a ±10 g capability could out fly many missiles, and an acceleration capability of ± 20 g will make the UCAV superior to nearly all missiles." This point is quite noteworthy.

Additionally, once the need to design for human pilots is removed, the design envelope truly opens up for substantial drag reduction, target cross-section reductions and signature suppression. Physical design improvements can also be coupled with tactical maneuvers and flight attitudes to reduce the cross section presented to an adversary. The study points to engineering estimates indicating that eliminating the need to design for a cockpit and an ejection seat will "allow a reduction in radar cross section by at least 12 dB in the frequency bands currently addressed, compared to existing aircraft", which in turn "reduce the effective range of enemy radar by a factor of two and area coverage by a factor of four."

The design envelope is further expanded by removing the human physiological constraints. Figure 2-4 shows the effect of sustained accelerations on humans.[6] The G-factor limits have not caused considerable problems in the past; however, with the advent of more sophisticated Surface to Air Missiles, more aggressive maneuvers are needed to break missile lock. Similar considerations apply to sustained use of divers and Sea-Air-Land teams (SEALs) in cold or hot water, and with strict diving depth limits. Extreme vibrations accompanying high-speed surface transit have also been known to cause a variety of severe musculoskeletal and internal-organ problems.

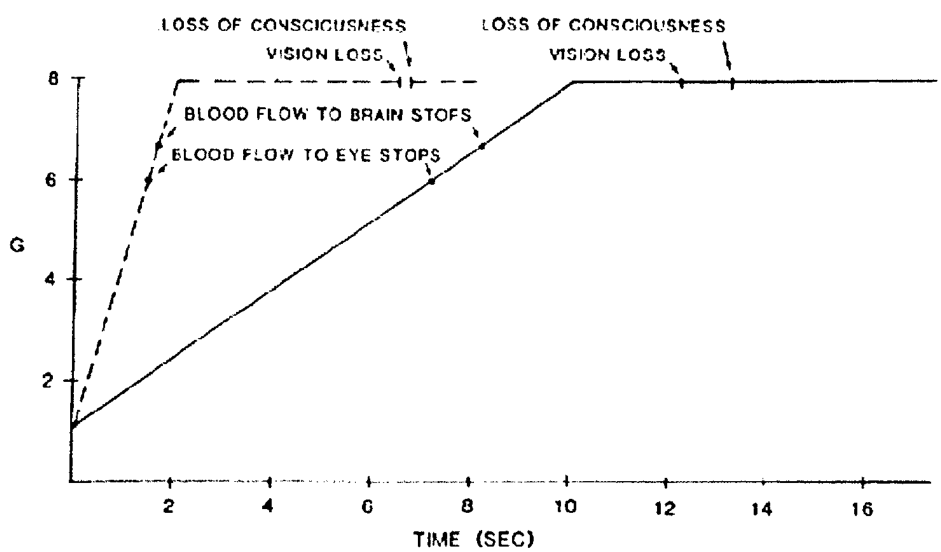


FIGURE 2-4. EFFECT OF SUSTAINED ACCELERATION ON HUMAN PERFORMANCE

In summary, the warfighting utility and advantages of unmanned systems have been identified and, in fact, have been demonstrated in specific cases, a recent example being the very successful application of Predator UAVs in the Balkans. More examples supporting these assertions are given in Section 3.0.

2.2.3 Political Reasoning

> War is merely a continuation of politics by other means.
> Carl von Clausewitz, *On War*

In his seminal book, Clausewitz clearly laid out and repeated the message of the connectivity of war and politics.[7] War is an extension of politics, but just as importantly, politics can be, and often are, dramatically impacted by war. Reflection on the unfolding of events in Vietnam, Somalia, and Kosovo reveals the dramatic impact of real or perceived casualties on the political will to continue military operations. Clearly, the threat or mere perception of potential American casualties gives great pause to both our military and civilian leadership. Consider an alternative where there are no American lives at stake. Could decisions to take decisive action occur quicker? Would there be any merit to faster decision-making?

Military commanders at all levels recognize that it is often the case that activities conducted early in an overall campaign can be decided with a smaller force, and with greater effect, if they are in fact conducted early enough. The idea of "Speed of Command" has been emphasized by VADM Cebrowski in his discussions of Network Centric Warfare.[*] The essentials are "decisively altering initial conditions, developing high rates of change, locking in success while locking out enemy alternatives". Decision-making processes slowed by lengthy debate over possible casualties reduce the benefits of speed of command. The same point has been made at the very highest levels of the Department of Defense in the Annual Report to the President and the Congress[3], which states that 21st Century naval engagements will be characterized by speed of command rather than by attrition.

Unmanned systems as augmenting warfighting systems are an essential element to accelerating speed of command. They provide the military and civilian leadership multiple advantages. They function as an improved defense layer that never sleeps and never gets tired. In contrast to situations, especially during crisis events where fatigue can cause young overextended sailors, marines, soldiers, and airmen to stray off in error or fail to maneuver away or simply duck, a machine casualty is not a CNN news item that can halt an administration in its tracks. Unmanned systems provide the opportunity to conduct physical preparation of the battlefield to accompany the intelligence preparation of the battlefield before the fleet arrives, absorb hits intended for the fleet, and, if necessary, prevent hits by taking decisive action. All these can be done at scalable levels, without the need to take into consideration U.S. casualties, hostage situations, and possible long-term prisoner of war (POW) complications. As we were the U.S. be stopped cold in its tracks if someone dragged a robot in the streets instead of a fallen U.S. serviceman?

---

[*] See briefing at http://spica.or.nps.navy.mil/netusw/CebrowskiNetWar/tsld009.htm. Speed of command has also been addressed in the March 1997 Department of the Navy White Paper "Forward ... From the Sea, The Navy Operational Concept".

The absence of potential hostages, POWs, and casualties makes the decision-making process much simpler and quicker. It makes a threat of U.S. intervention or follow-on action more realistic to opponents. It denies opponents cheap and easy domestic political victories. In short, it provides the U.S. political and military leadership many more options at all levels of conflict. It also removes many opportunities for global friction to develop and escalate as in the recent episode where a Navy's EP-3 and a Chinese fighter/interceptor made unfortunate physical contact.

Since the Vietnam conflict, another dominant trend has emerged in the body politic of the United States, namely a loudly voiced aversion to prolonged conflicts, especially where U.S. interests are not immediately apparent. A corollary to this aversion to prolonged conflicts is an even more pronounced aversion to casualties.

With today's communication technologies enabling determined global media outlets near-instantaneous coverage and exposure of any event, it is nearly impossible to predict what will be seen and heard by the public. It is therefore difficult to predict the consequences of public exposure of military activities. Media coverage invariably focuses on human casualties, especially when U.S. casualties and captives are involved. The broadcast of captive airmen during Desert Storm, the pictures of U.S. servicemen's corpses in the streets of Mogadishu, Somalia, and the capture of Army patrols on the Kosovo border serve to make this point.

2.2.4 Economic Reasoning

> There are three basic elements [to win wars] and in order of importance, they are: People, because wars are fought by people, not weapons. Strategy and tactics, because wars fought without innovational ideas become ... blood baths winnable or not. Hardware, because weapons that don't work or can't be bought in quantity will bring down even the best people and ideas.
>
> COL John Boyd (USAF – Ret)
> Testimony to the Senate Armed Service Committee, April 1991

Another significant emergent trend influencing "Next Navy" and "Navy After Next" is the increasing costs of research, development, acquisition, deployment, operation, and maintenance of new systems. In a number of programs one sees the attention given to this factor by the pre-fix "Low Cost" attached to a system name such as the Low Cost Autonomous Attack System developed by the Air Force Research Laboratory and Lockheed Martin Corporation.

One of the paramount considerations in defense planning is the actual dollar cost of defense. As a nation, we have a number of overall obligations, of which defense is prominent or even most prominent. The overall defense budget however, and the obligational authority provided by Congress, are always under scrutiny and always subject to justification and careful resource management. It is with this in mind that exploring the economic and cost implications of unmanned systems is of vital importance as a component of our discussion. The authors aim to highlight the economic benefits to be accrued from a systematic approach to unmanned systems.

In this section, general trends in the civilian sector show that automated/unmanned systems provide significant productivity increases at lower and lower costs. The main economic

considerations where intelligent applications of unmanned systems have significant contributions to make are: (1) lowering manpower costs, (2) facilitating efficiencies in recruiting, retention, and training, (3) allowing for economies of scale to have the room to manifest themselves, and (4) reducing the costs of overall logistic infrastructure.

While detailed analysis of the above factors merit their own specific studies, it is worth noting their importance and contribution to the case for unmanned systems.

2.2.4.1 The Cost of Manpower, Recruiting, Retention, and Training. From Congress we find "Recruiting/Retention: The Army and Navy missed their fiscal year 1998 recruiting goals while the Army, Air Force, Army Reserves, Navy Reserves, and Air Force Reserves all missed their fiscal year 1999 recruiting goals. Furthermore, each of the services has reported increasing difficulty retaining personnel in critical skill areas."[8] These words, and similar ones, are repeated with what should be extremely alarming regularity. The seriousness of this problem can be appreciated by the current situation the U.S. Air Force is facing in their recent call for volunteers from the recently retired ranks: "The Air Force has begun a volunteer program to bring 208 retired pilots, navigators and air battle managers back to active duty to fill key rated headquarters staff positions above the wing level. Those eligible must have separated from the Air Force at the rank of lieutenant colonel or below but have been retired no longer than five years."[9] This is a clear indicator of the graveness of the skilled labor situation.

In addition to the difficulty of recruiting and retaining appropriately skilled manpower, the Naval Research Advisory Committee (NRAC) states in its executive summary for the study on reduced manning that "approaches to reduced ship manning, without sacrificing readiness or jeopardizing mission, would be of great benefit inasmuch as manpower-related expenses combine to consume about 60% of the budget."[*] The NRAC also makes a very hard-nosed recommendation: "The Deputy Chief of Naval Operations (Resources, Warfare Requirements and Assessments (N8)) should revise the methodology for development of Required Operational Capability (ROC)/Projected Operational Environment (POE) to reflect an emphasis on manpower reduction through strict control of requirements. As technology is injected to automate ship functions, billet reductions should be generated and formalized during periodic document reviews." The costs of manpower and the opportunities for automation are formally recognized.

Manpower is expensive. It will become even more so as society develops and the basic standard of living rises. Manpower aboard ship (or other platforms) is recursively more expensive since ship design has to accommodate people, and serve and take care of those people. As crew sizes increase, additional non-combat crewmembers are required just to take care of the crew. These realities have been recognized in the commercial world where ship crew sizes have been declining while vessel size has been increasing, and in the design goals of a new generation of surface combatants such as ship class DD-21. This is also true on the aviation side (civilian and military), and in the design of ground combat vehicles such as tanks.

---

* http://nrac.onr.navy.mil/webspace/exec_sum/reducman.html (Reduced Ship Manning, November 1995) this is also reinforced in the year 2000 report "Optimizing Surface Ship Manning" which concludes: "Modify the ship design process to include Human Engineering so that optimal human/system performance is achieved with as few Sailors as possible."

Absent the military draft, the initial cost of accessioning and retaining new servicemen and women is increasing dramatically. Earlier, the report cited comments made by senior officials regarding recruiting and retention. The trends are not promising. Every year, recruiting and retention incentives and bonuses must be increased to attract and keep the increasingly valuable and knowledgeable military workforce. The skills that make individuals successful in their respective service specialties are highly valued in the civilian sector.

At the same time that individual billets are getting scarcer and more expensive to maintain, the world security landscape keeps evolving in ways that demand more attention. Simply stated, we are facing a situation where we need more individuals (who are more highly skilled and trained) to attend and respond to more challenges and contingencies, in more places, more often. We will neither have, nor be able to afford, the aggregate manpower required to address global responsibilities of the 21st Century with the technological, tactical, and strategic framework of the 20th Century.

As the pace of technological change accelerates and the battlefield becomes more complex, more frequent training, training updates, and retraining will be required. All these will require increasingly more expenditures of people and time.

Billet costs are not always fully appreciated. There are direct billet costs such as pay, allowances and retirement pay, and variable indirect billet costs including training, locating, and supporting. There's also the cost to the taxpayer (not shouldered by the Service agency) such as the GI Bill benefits and various DOD medical care costs. When looking at economic considerations, fully transparent accounting should be employed.

How do unmanned systems help? From the economic point of view, the appeal of unmanned systems based on a modular, standardized framework is that they offer a means both to predict costs and reduce the costs of 'doing business'. They also offer the inherent potential for rapid force structure scale up (or ramp up) in ways not possible with traditionally manned forces.

There are several considerations to take into account:

- Training with a set of standard systems and modules is much less costly than training with multiple systems that may not have much in common.
- More individuals trained with the same skills allow schedulers and planners greater flexibility than cases in which there are many individuals, each with unique skills that cannot be interchanged.
- The burden of updating tactics, techniques, and procedures can be shared between people and machines. As machines become more 'intelligent', individuals will require less machine-specific training, and will migrate to higher cognitive-assessment and decision-oriented skills. Changes in tactics and responses that in the past would require countless drill hours, would be achieved by updating unmanned systems' software. These software updates can occur nearly simultaneously and instantaneously across an entire force. Contrasted with traditional training approaches, time and cost savings could be rather significant.
- There is a very real potential to make effective use of the entire Naval Warfighting establishment, including active duty afloat units, shore activities, and naval reservists

in the heartland. As unmanned systems become more prevalent, their command and control may actually take place in rear areas, perhaps even in CONUS. One can envision a likely future where naval reservists, located in corn-belt states, actively participate in real-time to affect a battle many time zones away.

2.2.4.2 Economies of Scale. Col. Boyd's comment "weapons that don't work or can't be bought in quantity will bring down even the best people and ideas" * is significant in multiple respects. First, weapons and weapon systems must be designed in a way that they do work. As we move to the Network-Centric concept of warfare, the network must work as well as the weapon systems. In fact, the system-of-systems that is the collection of people, individual weapons, and the network must interoperate and work well as an entire system. This point is essential and is a key motivator for a coherent overall framework for unmanned systems development.

The next element articulated elegantly by Col. Boyd is the recognition and emphasis that must be given to buying high-quality hardware in quantity. Here's where modularity and standardization are essential. The theme is quite simple: it is considerably less expensive, as far as unit costs go, to produce items in quantity rather than in custom fashion or in very small production runs.

In 1936 T. P. Wright published an article describing a basic theory for obtaining cost estimates based on repetitive production of airplane assemblies.[10] There, he essentially argued that performers of repetitive activity learn from their activity and ultimately optimize to expend less time or effort on that operation. The Wright approach to cost prediction has been embraced under many different names such as "the learning curve" and "improvement curves". In particular, it's worth noting the significant attention to quantity-production-based cost savings given by DOD in *Contract Pricing Reference Guides*.[11]

If one uses the Wright Method coefficients for complex hardware with the learning coefficient or learning percent being 85%, one gets the trends depicted in Figure 2-5.[12]

To illustrate the above in concrete terms, if the production cost for a product with a production run of one unit is $100 the average unit cost for a production run of ten of the same units would be $58.28. In quantities of 100, the average production costs would be $33.97, in quantities of 1000 the average unit costs would be $19.79, in quantities of 1,000,000 the average unit costs would be $3.92 and that's just on the production side. On the training and maintenance side, similar if not more dramatic savings would be realized. These savings would come from reduced logistics costs (service, repair, availability, replacement) and reduced training costs. Fewer standalones mean fewer different training courses, more experience developed in shorter time, and more training time with a particular system.

The obvious question here is how many units do we really need in order to achieve all these savings. What happens if we don't need large production runs? Obviously one should have the goal of buying what's needed at the best overall price. However, if the choice is having

* COL John Boyd is credited with rekindling the Marine Corps' Maneuver Warfare approach. The quotes above are from testimony to the Defense Policy Panel of the Senate Armed Services Committee (SASC), April 1991.

a few each of many different but similar items compared to a similar total number of items but with modularity and standardization to reduce production costs, the answer is quite tractable and can be calculated.

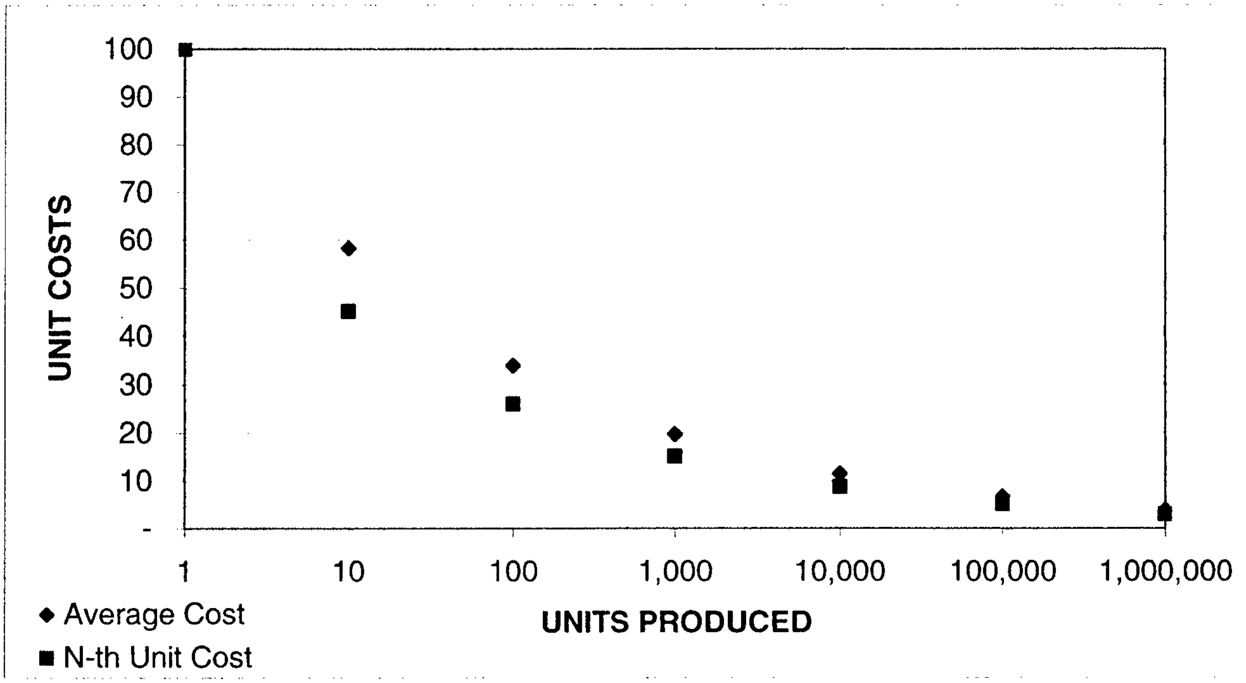


FIGURE 2-5. UNIT COSTS VS PRODUCTION VOLUME – USING THE WRIGHT METHOD

Consider an example in which approximately 1,000 items are required. Starting with the assumption that each item would cost $100 in quantities of one, if one purchased 1,000 of these items the unit cost would be $19.79 and the total cost would be $19,790. If one instead had ten similar, but individually produced items (same initial single item cost of $100), but now, buying 100 each of ten different items, the unit cost in lots of 100 would be $33.97, and the overall cost for 1000 items would be $33,970. If one had an uneven distribution among the ten items (i.e., some items produced in quantities of ten, some in quantities of 190, some in quantities of 100, etc.) the costs would start growing (with an outer limit, if every item was unique, of a cost of $100,000). At total item counts of 1000, the difference between total standardization (unit costs of $19.79) and total customization (unit costs of $100), the costs of total customization is over five times the cost over standardization. The training and logistics burdens would be even higher.

If one is about to embark on a new weapon or sensor development effort, it is entirely appropriate to pose questions regarding development costs and contrast a traditional (uncoordinated) approach with a standards-based modular approach. At first blush, it may well appear that if we were to develop only one system it would be less expensive to use the traditional "let me invent it all by myself" approach. This would be quite defensible for a single, isolated program manager who has no responsibility for the overall development of a variety of

weapon or sensor systems. The situation is entirely different if one is responsible for acquiring several weapon or sensor systems. For the program executives or the service acquisition executives who are responsible for expenditures across several weapon or sensor systems, or over larger budget account categories, the approach to uncoordinated development is much less justifiable. The lessons learned the hard way in the civilian sectors of the economy do have some very bright light to shed on this topic.

2.2.4.3 Implications to the Logistic Infrastructure. Earlier discussions concentrated on the benefits of a standards-based modular design and production considerations, and alluded to benefits accruable to logistics-related cost savings. The foundation to the logistics-related savings derives from the overall reduction of the total number of parts that have to be kept on-hand, inventoried, repaired, supplied, refurbished, and transported, to name just a few of the logistics-related considerations.

Fundamentally, the very nature of modularity provides for built-in interoperability, ease of replacement of fatigued or faulty components, ease of upgrades of components of systems rather than replacement of entire systems, and bundling of modules into super-modules that can be repaired or replaced as units. Recently, better understanding of the notion of supply-chain management and its acceptance within corporate America has led to the realization that modularity enables decoupling. What in the past may have been a situation of low availability of any one of 10,000 components that comprise a car, has translated into high availability of modules. Each one is assembled from many components but dealt with as one module once integrated and produced as a module. Tracking, identifying trends, and providing spares is much easier if one is dealing with ten modules that are replaced as modules, as compared with stocking, tracking, and providing spares of 1000 components that may vary from system to system. The general notion has been understood well by senior military and defense officials in their decisions to reduce the number of different classes of ships and planes in service. The very same reasoning makes the same if not more sense when one embarks on designing the first or next generation of unmanned systems.

Specifically one needs to keep in mind these major considerations: It is much easier to train large numbers of personnel on use, repair, and updates of modular networked systems compared with large number of legacy stove-piped systems. Just the fact that one is dealing with fewer overall components provides the potential to have more people trained to work with, service, and repair a much wider range of systems thus alleviating some of the skilled technician staffing issues. The use of a standard set of modules on different types of systems allows for a "spares readiness" profile. There the same modules can be used for multiple systems and actually reduce the total spares count that one needs to carry forward, but at the same time provide full spares availability. This by itself provides a true opportunity to eliminate the phenomena of "hangar queens", in which functioning systems have to be stripped of working parts in order to make a few systems "whole" and ready to fight.

With the above discussion in mind, it is entirely appropriate to call for and initiate logistics-oriented studies, and firm up the logistics-oriented design and assessment considerations that should be addressed in a standards-based development of unmanned systems.

2.3 THE IMPORTANCE OF STANDARDIZATION AND MODULARITY

Inherent in the case for unmanned systems made so far is the notion that they must be applied in very large numbers in a broad continuum across the full breadth of Naval missions to achieve their full warfighting potential for force augmentation. However, large numbers of systems are only affordable if they can take advantage of the economies of scale discussed in the previous section and these economies of scale can only be achieved by the application of standards and modularity. As will be seen in the next section, this is not a notion unique to the military.

2.3.1 Standardization

The importance of standards has been recognized through the ages since the time people established standard weights and measures in all areas of human endeavor. In fact, just the mere search for absolute standards of length and time are what gave rise to the concept and use of the atomic clock, which itself gave rise to the concept and then the reality of the Global Positioning System. As one observes carefully the places where tremendous progress in productivity has been made, in addition to automation and inextricably linked to it is the use of standards and standardization of parts, protocols, interfaces, definitions, and more, in an exceedingly wide span of activities.

How do standards help? In commercial and industrial applications, standards allow efficient design of a multitude of products with ease, certainty, and opportunity for economies of scale. Entire treatises can and have been written on this subject. Major national and international organizations have been created to coordinate, establish, guarantee, test, and protect standards.*

Standardization allows manufacturers the option for large production runs. Large runs provide the economic bases for lower costs. The economic benefits of standards were discussed in more detail in paragraph 2.2.4. The developmental and practical aspects of standards are such that they allow manufacture of component parts that can be easily connected to other parts and with little (if any) adjustment, cost, or time delay. It allows all parties involved with a particular enterprise to communicate and exchange information readily. This is why one can go into a hardware store, request and obtain nails, nuts, screws, bolts, piping, and so on, with the total certainty that if you ask for a particular size or dimension component, that's what you'll get.

* Some of the best known organizations are the United States Department of Commerce's National Institute of Standards and Technology (NIST), The American National Standards Institute (ANSI), and the International Standards Organization (ISO). NIST, chartered by the U.S. Congress on March 3, 1901, the National Bureau of Standards, was the first physical science research laboratory of the federal government. The recognition of the importance of standards was well established by that time. The catastrophic Baltimore fire of 1904, in which more than 1,500 buildings burned because of a lack of standard fire-hose couplings, drove home the point of the need for standards. After action investigation showed that firefighters from as far away as New York assisted, but few of their hoses fit the Baltimore fire hydrants. In total, it was observed that there were more than 600 sizes and variations in fire-hose couplings. Clearly not an efficient way to fight fires if you're planning on getting outside help. The result was selection and establishment of national standards for fire hose couplings. Is there something to learn here?

While the early periods of the last century were predominantly concerned with standardization of mechanical and electrical components and processes, the last part of that century was shifting to standardization in the information technology and information transfer arena. Without a clear set of television standards, for example, there would be no hope of designing television recording equipment, transmission equipment, and reception equipment. On the consumer side, it would be totally ludicrous to contemplate having a different TV set for each broadcast station, and to try to plan different broadcast antennas and TV picture formats for each possible brand.

Sometimes, this lesson takes a while to take hold. In the early days of facsimile (fax, or telefax) transmission over telephone lines, different vendors created different equipment designs. What this meant was that if you wanted to receive or transmit a fax, you had to make sure that the office or person at the other end had a compatible machine (typically made by the same vendor). It wasn't until about 1980 when the Group 3 Standard was created by the Comité Consultatif International Téléphonique et Télégraphique (CCITT, now known as ITU).** The Group 3 Standard was adopted to ensure the compatibility of digital machines operating through public telephone systems worldwide and assumes a standard letter-size sheet scanned by a strip of 1,728 photosensors across its width. The Group 3 protocol specifies CCITT T.4 data compression and a maximum transmission rate of 9,600 baud with two levels of resolution: 203 by 98 and 203 by 196. While most of us may not be aware of the information standards protocols, by now most of us are using (through our equipment) standard protocols such as V.90 for full-duplex modems sending and receiving data across phone lines at up to 56,600 bps, X.25 packet-switching protocol for wide area networks, X.400 protocol for e-mail (with "POP3" or "SMTP"), and X.500, which defines e-mail addressing formats. Of course, all these standards and protocols continue to evolve and eventually will be replaced, but during their time of use, one could not imagine information networking without them.

With the advent of the internet, there have been increasing numbers of protocols for document definition and packet switching such as File Transfer Protocol, Hypertext Transfer Protocol, Transmission Control Protocol/Internet Protocol, Hypertext Markup Language, and Extensible Markup Language. On the computer hardware side the standards abound as well, "RS232" and "IEEE 488" were some of the early (mysterious) input/output port standards, now "USB" and "Firewire" have become household terms. Computer monitor standards are now a coin of the realm. There were days when no one knew what "CGA" meant (IBM's Color Graphics Adapter standard 320 x 240 pixels), but now "VGA" and "XGA" are better known. The 5-¼ and 3-½ floppy disks were size standards and "DOS" was an operating system and disk formatting standard.

In the software world, unless one wanted to copy results and key in data in an extremely slow manual process, input and output is formatted to different levels. The idea of formats is itself that of standards to assure consistency. An often-used standard is the Structured Query Language (SQL) used to communicate with a database. SQL according to the American National Institute of Standards (ANSI) is the standard language for relational database management systems.

** CCITT is the *Comité Consultatif International Téléphonique et Télégraphique*, an organization that sets international communication standards. It is now known as ITU.

The Navy is currently planning its future and committing very large investments to an information standards-dominated approach. The whole of Network-Centric Warfare cannot exist without networks; networks that must rely on the previously discussed standards.

Perhaps some of the most ubiquitous standards around are those of electrical power transmission and connection including 110 Volts/60 cycles AC, 9-Volt batteries, C and D cells, and 12-Volt car batteries.

Standardization in transportation is of particular importance and significance. Almost every adult is aware of the importance of standards in transportation in daily life. The octane rating of the gasoline, the grade of oil, the dimensions of tires, the traffic signs and signals on the road, the width of lanes, and the heights of overpasses; all these are set to standards. We almost never think of those as standards, but they are. One is more acutely aware of the gauge of railroads. Trains wouldn't run very far if there weren't consistent standards.

Perhaps more than any service, the U.S. Army takes roads, transport vehicles, and related standards into careful account. Invisible to many, but of acute interest to military logisticians, is the consideration of moving freight and cargo. At the end of the day, those who have fought extensive battles know that supplies and resupplying sites are important.

The idea of using standardized containers is a particularly important one, and will be discussed in detail in Section 5.0. The utility of standard containers in moving freight is by now a classic story that has many ramifications for the Naval Readiness Augmentation concept. Malcolm McLean, the inventor of the containerization concept, came up with the idea after asking himself "Wouldn't it be great if my trailer could simply be lifted up and placed on the ship without its contents being touched?"[13] It was not until 1956, 20 years later, that the first scheduled transit ship carrying containers, the *Ideal X*, sailed from Newark, New Jersey.

Prior to McLean's breakthrough, all commodities (except bulk commodities) were moved piece by piece: boxes, individually loaded onto a truck, were individually unloaded dockside and then hoisted into the hold of the ship. The process was reversed at the destination, where the boxes were individually unloaded onto a truck or train for delivery. With McLean's approach "A trailer carrying numerous boxes could be loaded at the shipper's door, sealed, sent by truck to the port, lifted off its chassis and simply stored aboard ship" and likewise unloaded and delivered to its ultimate destination.

A key and crucial aspect of containerization and true intermodality was standardization of container sizes and fittings. At the time, the maximum size for trailers allowed on the U.S. highways was 35-ft long by 8-ft wide by 8-ft high. Later on, industry adopted what are now the ISO standards of 20- and 40-ft long units. In any case, the availability and adherence to dimensional standards meant "any box could lock on to any other box, trailer chassis or ship."

The first practical test of McLean's containerization concept came with initiation of the first trans-Atlantic container service aboard Sea-Land's *SS Fairland*. It was a resounding success; cargo aboard the *SS Fairland* arrived in Europe four weeks faster than its equivalent had before. The upshot was that new vessels and business models and practices were tuned to intermodal container cargo transport. Nowadays, vessels can carry 6600 twenty-foot equivalent units (TEUs), about 40 times the capacity of the first containerized ships, and larger ships are in

design and construction. They can also be loaded and unloaded using much less labor and time. What took a crew of 20 longshoremen loading 20 tons in one hour is done in minutes with a crew of ten and gantry cranes.

Ultimately Sea-Land's initial standard of 35-ft long containers (derived from the maximum legal trailer lengths for highways) ended with the industry standardized on 10-, 20-, and 40-ft long containers originally recommended by the American Standards Association in 1961. In 1965, the standard was adopted by the International Standards Organization (ISO) and is the basis for the standard container unit of measure, the TEU.[14]

In the warfighting arena, what one knows as "tactics, techniques, and procedures" (TTPs) and doctrine are themselves standards of warfighting. It is the availability of such standards that allows commanders and warriors to know what "parts" of warfighting fit with other "parts", and what to expect as a result of using these "parts." The Department of Defense has formally acknowledged the criticality of standards by chartering a Defense Standardization Program headed by an O-6 officer with service standardization executives responsible for service-specific issues. DOD regulations require program managers identify early on in their program, relevant international standards to assure interoperability.

Careful reflection offers the following observation: *In an extraordinarily large number of arenas of human endeavors, especially those involving tangible (rather than artistic) use, standards ultimately come to have a large and beneficial role.* If one is to embark on increasing capabilities of any type, one is best advised to incorporate standards-based thinking early in the conceptual and physical design and development process.

2.3.2 Modularization

In this section, we introduce and discuss in detail the concept of modularity.* Modularity is a key ingredient for effectively meeting current and emerging requirements. Reviews of major successes in industrial, commercial, and even military endeavors all point to modularity as a foundation of enduring capability, effectiveness, and success. The desire to benefit from the power of design, production, and use of modularity is one of the pillars of our unmanned systems concept.

The distinctive features of items that are modular in nature are: a) they are made up of distinct parts, or modules, and b) the modules are standardized. While these two attributes may seem trivial, they are extremely powerful. That an item is made up of modules allows replacement of individual modules for repair or upgrade with ease. That items are standardized, as discussed earlier, allows full trust that all similar items and similar modules will work in the same way and perform equivalently.

In military and other organizations, the notion of modularity is implicit in the organizational structure. Combatants of a certain type are interchangeable modules, and sailors and officers of certain disciplines are modules of crews. When one replaces a ship or sailor with an equivalent ship or sailor and maintains the same unit capability, one is making use of

---

* The word modular is defined as "constructed with standardized units or dimensions for flexibility and variety in use".

modularity. This is true in any large organization and is true for complex systems, objects, and artifacts, as well as entire military establishments. The emphasis on modularity is well deserved.

Modularity is becoming recognized as a core principle for design, production, and use across many systems, products and enterprises.[15,16] So, what is a module? The concept appears intuitive, yet it is one that needs successive levels of definition to appreciate. A module is probably best viewed as a part or component of a larger structure or system. It is a unit whose internal components are strongly or tightly connected among themselves, but weakly connected to other external units. Baldwin and Clark offer several definitions such as "Modularity is a particular design structure, in which parameters and tasks are interdependent within units (modules) and independent across them".[16]

A tangible example of a modular system is a car, which is made up of distinct units such as tires, wheels, chassis, engine, transmission, steering wheel, seats, air-conditioning, lights, etc. The car as a modular system demonstrates some of the key benefits of modularity in a direct way. Tires can be designed, produced, mounted, and replaced without too much concern about the car's engine. The tires can be (and are) designed and produced quite independently of the engine. The tires can be replaced at any time without having to replace the battery. When better, higher-performing tires are available and needed, these can be mounted without replacing the windshield wiper. In other words, modularity provides a great deal of independence of one part of a system from another and several other advantages. We will discuss those advantages in detail next.

Why adopt modularity? A considerable amount of writing has been done on the topic (most recently Baldwin and Clark, and O'Grady), and even a larger amount of implementation practiced. The main reasons are that for large, complex endeavors, it allows faster product development, much lower cost, and greater flexibility than alternative approaches. Specifically, it allows one to limit development to identifiable modules, decouple and parallel design tasks, decouple and parallel production tasks, significantly speed up the process of overall product development and product improvements, significantly improve the ability to maintain, repair, and dispose of modules (without having to do so at the integrated-product level), reduce capital costs, provide for economies of scale (addressed in paragraph 2.2.4.2), and provide for rapid development of a truly rich variety of products based on integrating alternative module variants.

Does the modularity approach actually work? Well, every time one pulls an aircraft engine out of a fighter plane (for service or overhaul) and sticks another one into it (to maintain combat readiness), one is benefiting from modularity. In fact, modularity has become so positively recognized that products incorporate the term modular in their naming, as in the case of Motorola's Digital Modular Radio (DMR).* O'Grady reviews and discusses a number of other prominent case studies of modularity. He cites Nippondenso being able to build products for next-day delivery using a modular approach incorporating the Microsoft CE operating

* In 1998 the Navy awarded a five year, Indefinite Delivery Indefinite Quantity (IDIQ) contract valued at US$337 million to Motorola Systems Solutions Group for a new, digital, software-programmable radio. "Motorola's DMR solution will replace nearly a dozen incompatible radios, reducing operating costs and space requirements. It also will help the military in satisfying its need for interoperable communications. It will enhance the ability of the armed forces to intercommunicate with each of its sister services, which traditionally has been a problem since each service uses different frequencies, bandwidths, and waveforms." http://www.motorola.com/GSS/SSTG/press1998/0923dmrcontract.html.

system, as compared with several weeks' delivery when using a non-modular approach. Another example is Boeing's use of a modular approach for design and assembly of Delta IV rocket launcher variants, allowing a wide variety of launch and payload options, and saving approximately 50% of launch costs. IBM, Microsoft, and Sun all use modularity in their products in significant ways. In fact, O'Grady cites a case where Boeing had to learn the hard way (at a cost of $2.6 Billion) the costs of not being modular. He describes Boeing's experience on the 747 as essentially having to go to extreme manual redesign every time a customer made a different choice in bulkhead placement (with the attendant placement decisions for over 2500 parts and almost 1000 pages of drawings that had to be annotated or tabbed). By contrast, the Airbus A330 and A340 were designed with modularity in mind for production by the partner nations and assembly in France. The assembly statistics tell the story. Boeing needed 216 workers per plane while Airbus could do a similar job with 143 workers per plane. By 1998 Airbus had become a major rival to Boeing with 50% or more of the product market.

The more readily immediate experiences with modularity are in the area of computers, and more recently, personal computers. As described by Baldwin and Clark, the first major modular enterprise occurred at IBM with Standard Modular System (SMS) circuit design, packaging, and manufacturing technology. The SMS incorporated many standardization features such as: (1) all circuits were constructed on 2-½ x 4-½ in cards, (2) each card had 16 tabs on one 2 -½ in side, (3) the cards plugged into sockets in a standard box (case), (4) parts such as transistors, resistors, etc. were inserted on one side of a card and soldered on the other side of the cards, and (5) the design for specific cards (with specific tasks) were standard designs. Later, when the Solid Logic Technology (SLT) came about, the SMS modular design process was extrapolated to SLT design, which was then the basis for the IBM System 360.

What the technologists at IBM were doing came in time for the market demand that emerged. Once the commercial and industrial sectors recognized the utility of computers, more and more was demanded of computers; however, the products originally available were custom designs for hardware and software, requiring significant reinvestment of capital and programming effort for every new major technology upgrade or scale of effort expansion. The problem as it had been expressed was the ever-growing complexity of systems and interdependent structure of their design. The IBM sales force was continually telling management that customers were very unhappy with this state of affairs, and the increasing costs of maintaining multiple, incompatible computing machines and programming staffs. Almost every computer had software that was custom-designed to utilize the specific design of that computer (today we would call that extreme platform dependence). Of the eight different systems sold in 1960 by IBM, six had unique data formats and instructions sets. Consequently, they were incompatible. IBM organized a team to examine this issue and develop "an over-all IBM plan for data processor products". The result of this effort was a recommendation *to replace the entire IBM computer product line by a new family of modular compatible products.* The new product family was the IBM System 360.

The 360 family was governed by the following design rules:

- Any program written for one configuration will run on an equal or larger configuration.
- Any program compiled on one machine will run on another machine.

- Each processor must operate correctly with all machine language programs of all the other processors, with same or smaller Input/Output (I/O) and memory configurations.
- To any I/O device, all channels will appear identical except for the data rate.
- A single method for memory/central processing unit coupling will be developed and applied to all processors.
- A single I/O control structure will be provided for the entire family.

Obviously, these are the high-level rules, with more intricate subordinate design details. However, this approach and the IBM System 360 allowed IBM to be extremely profitable and dominate the mainframe computer industry and market.

This approach was repeated again when personal computers (PC) came into being. While a number of custom approaches (ALTAIR, APPLE PC, Tandy's TRS-80, and others) were introduced prior to IBM entering the market in 1981, it was not until the IBM PC's introduction of a standard box with modules having standard, published interfaces that the personal computer market took off. IBM defined an architecture with standard interfaces that allowed modules to operate together to create a synergetic whole – a working personal computer. The independent modules were the power supply, motherboard, processor, video card, printer card, sound card, floppy-disk and hard-disk controllers, floppy disks and hard disks, and monitor. Also included was the chassis or computer box with standard bus interfaces. Anyone could literally interconnect any compatible card or module. One could add a printer of their choice. They could also add a modem or a network interface card. If they wanted any one of many other specialized cards that were designed by independent vendors, they could get them and plug those in, as long as they fit the standards and module definitions. The software situation was similar. The result was that, going from being a nation where few people encountered computers, we've become a nation dependent on computers at home and work. All of this was possible thanks to standards and modularity. What happened to those companies who didn't adopt the standards and modularity approach? They either vanished or continually lived at the edge of a financial abyss.

Not surprisingly, the experience encountered by computer-hardware developers has been encountered by software developers. The case histories in the world of computing software and software development languages at organizations such as Bell Laboratories (developers of UNIX), Microsoft, and SUN, to name a few, have all been identical. Modularity is the key; if one pays attention to the software practices in industry and academia, one encounters terms such as reusable modules, object-oriented design, and object-oriented languages. All these are testaments to the primacy of modularity in our technological future.

Today, the U.S. Navy is basing its future on computers and networking (Network Centric Warfare, C4I) implicitly adopting modularity in planning for the future. With this as background, we recognize the importance of an approach that brings modular design as a pillar of conceptual development through the front door, rather than slowly gravitating to modularity after discovering the pitfalls of complex, interdependent (and usually non-interoperable) systems.

Yet, as one examines the landscape of unmanned vehicles, one cannot escape the absence of modular design. In fact, except for a very few special cases, most designs are non-modular and non-scalable. In some cases, one might observe distinctions of platform and payload, and

some effort is underway to accommodate modular payload packages. For the most part, modular design has been more of a very distant vision rather than a basic design practice.

Our approach to naval readiness augmentation via the unmanned systems path takes modularity as a point of departure. Accordingly, we specifically set out to examine naval missions, tasks, and required capabilities with a view of defining a set of modules (limited in number) to address those required operational capabilities. The modules would allow rapid design and construction of unmanned systems by use of a subset of these modules tailored to the mission (i.e. creating a mission package).

Our approach results in approximately 39 distinct modules. The mapping of warfare areas, needs, and missions to the underlying set of modules is by no means unique. Using other assumptions or individuals might result in a different collection of modules. The significance of our work lies in pointing the way ahead in describing the potential advantages and desirability of using a modular standards-based approach. It also provides a specific implementation approach should the Fleet and Navy desire to embrace this effort in earnest.

Other considerations need to be made in discussing modularity. The most important considerations are architecture and interface standards. We leave these discussions to a later date.

2.4 A LARGER CONTEXT OF BROAD TECHNOLOGICAL TRENDS

The advent of unmanned systems for military purposes can be viewed in a broader context, which shows that the unmanned concept is not a radical new idea, but in fact only a small adjunct of a much larger technological trend across modern civilization.

It is very worthwhile to look over the fence and observe the dominant trends and practices in other sectors such as agriculture, manufacturing, commerce, and industry. The question to ask here is "are there major sector practices that have been put to exceptional use from which DOD can benefit?" The answer is quite clear: there are several trends that stand out and contribute significantly, across the board, in entire economic sectors. The ones perhaps appreciated more by the civilian sector than the defense sector are those of automation, standards, and modularity.

There has been an underlying trend in the Defense community to make use of automation, standards, and modularity in design considerations. However, to date there has not been a systems-oriented approach consistent with their inherent potential.

To fully appreciate the potential for unmanned systems beyond transient fads, it is important to provide rigorous theoretical foundations that take into account the requirements aspects, as well as the associated opportunity aspects. Also, while the end potential of automation may appear intuitive, the actual scale and significance can only be appreciated by reviewing specifics. Accordingly, we include some historical as well as quantitative perspectives regarding machines, mechanization, and automation.

In this section we examine some of the trends and impacts associated with automation, standards and modularity, and discuss their potential to form the basis for a coherent framework for designing both a warfighting architecture and a tangible collection of systems of significant value for the Armed Services, and the Department of the Navy in particular.

2.4.1 Automation

> Main Entry: au·to·ma·tion
> Function: noun
> Etymology: automatic
> Date: circa 1948
> 1 : the technique of making an apparatus, a process, or a system operate automatically
> 2 : the state of being operated automatically
> 3 : automatically controlled operation of an apparatus, process, or system by mechanical or electronic devices that take the place of human organs of observation, effort, and decision
>
> Meriam Webster's Collegiate Dictionary
>
> Automation has revolutionized those areas in which it has been introduced, and there is scarcely an aspect of modern life that has been unaffected by it.
>
> Encyclopædia Britannica

Since prehistoric times, in quest of conquering the environment and at times fellow men, man has pressed into service an ever-increasing array of tools. Starting with simple tools and progressing to simple machines such as the wheel, lever, wedge, screw, and pulley, we notice an ever-accelerating trend of amplifying human physical (and later, mental) capabilities. The first machines were used to amplify one's direct muscle power. The next generation of technology was designed to use beasts-of-burden to augment one's muscles. Next in the progression was development of powered machines that didn't require human or animal muscle. Now, we are in the midst of an era in which machines can augment and amplify human cognitive abilities and, in many cases, perform entire tasks without the direct presence of humans.

If we consider the dictionary definition of *automation*, we would observe that the essence of automation is "the controlled operation of an apparatus, process, or system by mechanical or electronic devices that take the place of human organs of observation, effort, and decision". While at first this may be disturbing to some, consider the historical progression:

mechanisms → machines → automation → autonomous machines →systems of autonomous machines

The term automation came into being rather recently (about 60 years ago) in the automobile industry where automatic devices and controls in mechanized production lines were put into use for increasing productivity, reducing manual labor and increasing profitability. However, the underlying concept really made its appearance with James Watt's flying-ball governor, which eliminated the need for a human operator to open and close the valves on steam engines. Ever since that time (loosely referred to as the beginning of the Industrial Revolution), increasingly complex machines have been invented and put into wide use. The basic features found in machine automation are: (1) sources of power, (2) control mechanisms, typically feedback control, and (3) programming.

2.4.2 Industry

In the industrial arena, one has seen the development of robotics originally based on numerical control and teleoperation. Since the first numerically controlled machining tool was demonstrated at MIT in 1952, almost every modern factory has some numerically controlled machine or process in place, with some factories being totally automated. Industrial robots had their beginnings in 1961. They were made by Unimation, Inc. and were used to unload parts in a die-casting operation. Today, one sees a variety of industrial robots in action, from spot welders to inspectors of finished products.

2.4.3 Agriculture

The impact of mechanization and automation in agriculture has been astounding. The first successful gasoline tractor debuted in the United States in 1892. By 1950, there were 3,400,000 tractors. The power takeoff enabled farmers to cultivate planted crops mechanically. Complex unit machines (such as the grain combine) that allow entire tasks to be performed by one self-propelled machine have reduced the demand for manual labor by an unprecedented level. These unit machines are used in a variety of jobs such as harvesting tomatoes, picking cotton, baling hay, and picking corn (some of the modern corn pickers can pick twelve or more rows of corn at a time). Today's self-propelled mechanical tomato harvesters can electronically sort and automatically pack tomatoes.

Figure 2-6 captures summary statistics of population occupation over the last few centuries. According to the U.S. Statistical Abstract and Department of Agriculture Information, in 1790 the U.S. population totaled 3,929,214 individuals of which 3,727,559 were rural (and presumably engaged in agriculture).* In 1999, the U.S. population totaled 272,690,813, and the farm labor population, according to the Department of Agriculture, totaled 2,977,000 individuals. Today, one farm laborer, with the aid of machines and automation, produces at least 100 times as much as one 200 years ago. This is but one indicator of the significance of automation.

In 1982, the Chicago Stock Exchange revolutionized the brokerage community with the launch of the MAX system, one of the first automated brokerage trading execution systems. Since that time (and probably before then), many security and investment firms have engaged in *Program Trading*, in which automated, computer-model-driven stock trades are made based on quantitative strategies that buy and sell numerous relatively small baskets of stocks based on complex models of the market's internal workings and stocks' historic and theoretical relationships. This is thought to have been one of the causes of sharp stock market fluctuations and has been the subject of detailed analysis by the Securities and Exchange Commission.[17] However one wishes to interpret financial movements, it is clear that a substantial portion of the Nation's wealth is entrusted to the automated workings of computers and electronic systems.

---

* Obviously, if these numbers represent the total population, then only a fraction (above a certain age) would be participating in agriculture. Presumably in a rural environment, anyone above the some age, perhaps the age of 10 would have contributed in some capacity to their family's subsistence. Based on that and life expectancies is would be possible to determine the actual numbers that participated in agricultural production.

Given the volume of daily financial transactions and the rapidity with which transactions are executed, it is clear that these achievements would not be possible without substantial (if not full) automation.

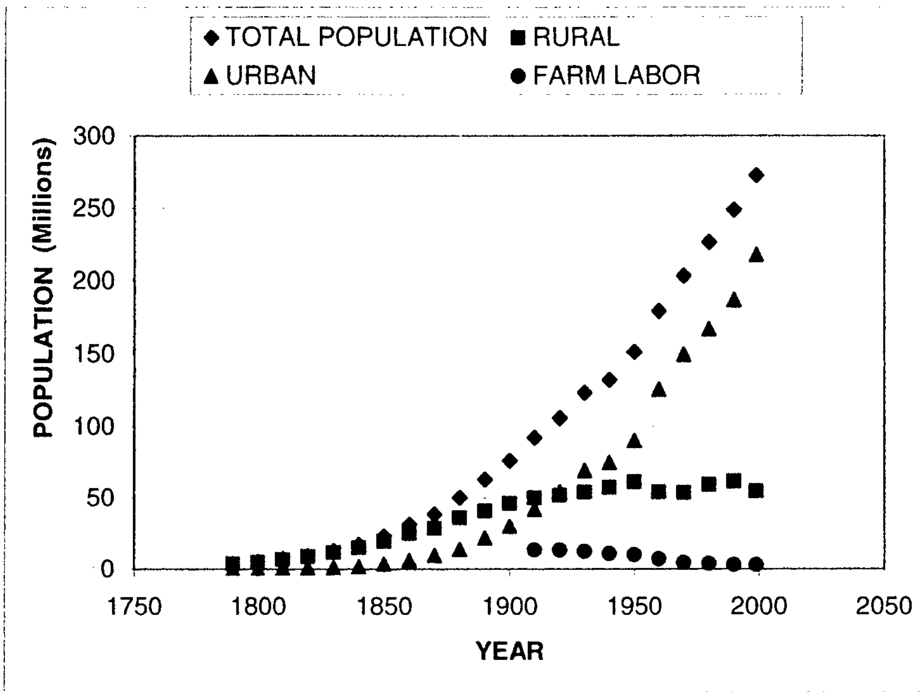


FIGURE 2-6. POPULATION STATISTICS IN THE UNITED STATES

2.4.4 Finance

In the past twenty years, computers, quantitative models of the economy and the market, electronic communication networks, and the trust of the users in the electronic automated market system have enabled the United States economy to grow to unprecedented levels.

Closer to home, many supermarkets and other retailers utilize automated inventory-tracking systems that allow entire organizations to monitor sales and inventories in real time and propagate the information through their entire supply chain. This capability, sometimes bundled together under the term "Just-in-Time", allows tremendous reductions in costs through optimized inventory management, timely purchasing and production, reduction in overhead associated with oversized warehouses, interest costs tied up with static inventory, and optimal use of staff and employees.

2.4.5 Space Program

Some of the best examples of automation come from the space program, in which independent machines are sent to locations many hundreds of millions of miles away from earth. Space machines and planetary landers operate independently, in unknown environments, for

periods that may extend into months. Some of these automated machines and vehicles have actually performed well beyond their expected lifetime with minimal human remote control.

Since its inception, the space program has used unmanned systems to test activities and conduct measurements first. The human factors, weight, and risk considerations all pointed to unmanned systems. Today we have hundreds of unmanned systems in space – they are called satellites. With the aid of autonomous control, they have achieved remarkable feats. Some of these unmanned systems cost in excess of $1B each (e.g. the Hubble Space Telescope). Clearly, our nation has learned to place trust in and rely on unmanned systems in space.

2.5 SUMMARY

The trends toward manpower constraints, casualty aversion, and economic factors combine to provide a strong motivation for systematic exploration of alternatives to standing warfighting paradigms. Unmanned systems can and should be used to address many of the concerns and considerations associated with these trends, and as a key instrument of necessary changes in Naval approaches and concepts. The remainder of this report amplifies the discussion of approaches to development of a coherent framework of unmanned systems materiel research, development and acquisition, and outlines warfighting concepts of operation for unmanned systems.

SECTION 3.0 UNMANNED SYSTEMS PROGRAMS IN DOD

3.1 HISTORY AND EVOLUTION OF UNMANNED SYSTEMS IN DOD

An extensive variety of UAVs, unmanned undersea vehicles (UUVs), unmanned ground vehicles (UGVs), and unmanned surface vehicles (USVs), have been developed in the 20th Century and are being marketed for a variety of applications. The first and consistently dominant customer of unmanned vehicles has been the military. Early military interest was focused predominantly on unmanned weapons and target drones. However, the second half of the century has seen an explosion of broader reconnaissance-related applications fostered by the revolution in information and sensor technologies. The United States DOD continues to be the dominant customer and generally represents the "cutting edge" developer for most unmanned systems technologies. However, non-military applications and customers are not trivial. Most UUVs are produced for non-military applications such as undersea oilfield service, dredging, cable laying, etc. Although the current market for UAVs is predominantly military, the recognition of UAVs as a "poor man's satellite" for remote sensing and earth resources monitoring is spawning a growing trend toward non-military development for a host of geographic information systems applications such as forest and agriculture monitoring, fishing zone and littoral water resources monitoring. Consequently, as this trend grows, a shift from DOD-dominated development to commercially dominated development of unmanned systems technologies will become increasingly evident, much as happened with the electronics and computer industries. Today's acquisition focus on leveraging commercial technologies and on affordability is already impacting DOD unmanned systems development. As commercial activity grows and spawns new unmanned systems technology components, DOD will be able to expand the insertion of these off-the-shelf technologies into military unmanned systems to reduce system lifecycle costs.

This section provides an illustrative overview of the history and current state of unmanned systems within DOD. It attempts to identify the major trends and systems to provide some background and perspective for the concepts espoused in this technical report.

3.2 UNMANNED AERIAL VEHICLES

The first unmanned drones emerged less than a decade after the first manned flight at Kitty Hawk, in time for World War I. Figure 3-1 reviews the evolution of UAVs that followed. The first UAV weapons emerged in World War II as the Germans introduced the V-1 Buzz Bomb, an early type of cruise missile.[18] The U.S. Army Air Force quickly followed with remote-controlled bombers filled with explosives, and from there the unmanned weapons evolution proceeded with the cold war development of ballistic missiles followed by highly accurate cruise missiles, smart bombs, and precision strike weapons.

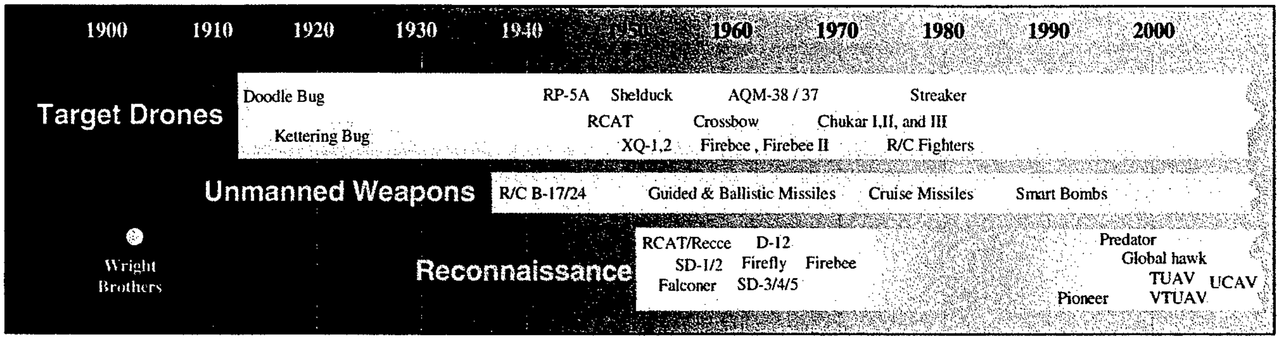


FIGURE 3-1. OVERVIEW OF UNMANNED AIR VEHICLE (UAV) HISTORY AND EVOLUTION

Target drones continued to be developed and improved, and remain in extensive use today. Starting in the early 1950s, the U.S. Air Force started investigating strategic reconnaissance drones with an adaptation of the radio controlled aerial target drone, and the U.S. Army started developing small tactical surveillance drones. However, strategic reconnaissance UAVs languished during the 1960s and 1970s due to the success and priority of the U-2 and SR-71 manned reconnaissance programs. The Army tactical UAV systems were eventually terminated during the 1970s without being fielded, because the operational commands did not accept them. One notable exception to this slow acceptance of reconnaissance UAVs in general was the extensive and very successful use of the BQM-34 Firebee and low-altitude 147-S Tomcat reconnaissance drones during the Vietnam War. BQM-34 drones flew over 3400 sorties with greater than 95% mission success, and 147-S drones flew over 2000 sorties with greater than 90% mission success.[18]

U.S. interest in unmanned reconnaissance vehicles continued to decline and, by 1981, no UAVs except target drones were operational in DOD, as evident in the fading of the reconnaissance UAV timeline in Figure 3-1. However, the U.S. successes with reconnaissance drones in southeast Asia had caught the attention of Israel, which started developing and deploying small tactical reconnaissance and decoy drones in the 1970s, culminating in the development and successful deployment of the Pioneer UAV in the 1980s. This generated a resurgence of interest in tactical reconnaissance UAVs in the U.S., with the Navy using Pioneer UAVs as spotters for targeting battleship fires during Operation Desert Storm. Pioneer continues to be deployed by the Marine Corps and is currently being adapted for airborne mine countermeasures applications (Pioneer/Coastal Battlefield Reconnaissance and Analysis [COBRA]).

Around the end of the 1980s, DOD established the UAV Joint Project Office within the Navy's Program Executive Office for Cruise Missiles (PEO [CU]), now PEO (W). The first UAV Master Plan was promulgated in 1989 and was followed by five subsequent editions through 1994. At that time, the Defense Airborne Reconnaissance Office began publishing a series of UAV annual reports from 1995 through 1997.

DOD interest continued the revival with a 1994 Advanced Concept Technology Demonstration (ACTD) that led to the development of the Predator UAV, which was successfully deployed in Bosnia in 1995 and 1996, and is currently in full production and continued deployment. The retirement of the SR-71 and a need to bridge the gap between the

TR-1/U-2 manned strategic reconnaissance aircraft and satellites led to the subsequent pursuit of several reconnaissance/surveillance UAV ACTDs, including the joint-service Outrider, the Tier II+ Global Hawk, and the Tier III Darkstar, the latter being terminated prior to completion of the ACTD. The General Accounting Office (GAO) found that since the Vietnam War, DOD initiated over nine UAV acquisition programs that were eventually cancelled, with an investment of over $4 billion. The cancelled programs not indicated in Figure 3-1 included Amber, Aquilla, Compass Cope, Compass Dwell, Condor, Hunter, Raptor, a classified program, and the Medium Range UAV.[19]

Today, the significant ongoing programs include Predator, Global Hawk, the Army's Tactical UAV, the Navy's Vertical Takeoff UAV (VTUAV), and the DARPA/USAF Unmanned Combat Aerial Vehicle. Currently, Navy UAV development is proceeding under the leadership of OPNAV N75, PEO(W), and NAVAIR PMA 263. Oversight is provided by the Naval UAV Executive Steering Group. Under this leadership, the Naval UAV roadmap and long range plan continue to be pursued.

3.3 UNMANNED UNDERSEA VEHICLES

Robert Whitehead, the father of the torpedo, designed the first unmanned, self-propelled, underwater vehicle, packed with explosives, in 1866 and thus launched the evolution of torpedoes that continues today.[20] Nichola Tesla developed what is termed the first autonomous undersea vehicle in 1898 and he predicted at the time that they would someday be "produced capable of their own intelligence and their advent will create a revolution".[18] Figure 3-2 provides a representative overview of the evolution of UUVs since those early times. Unlike UAV development, serious investment in UUVs did not begin until the 1960s.

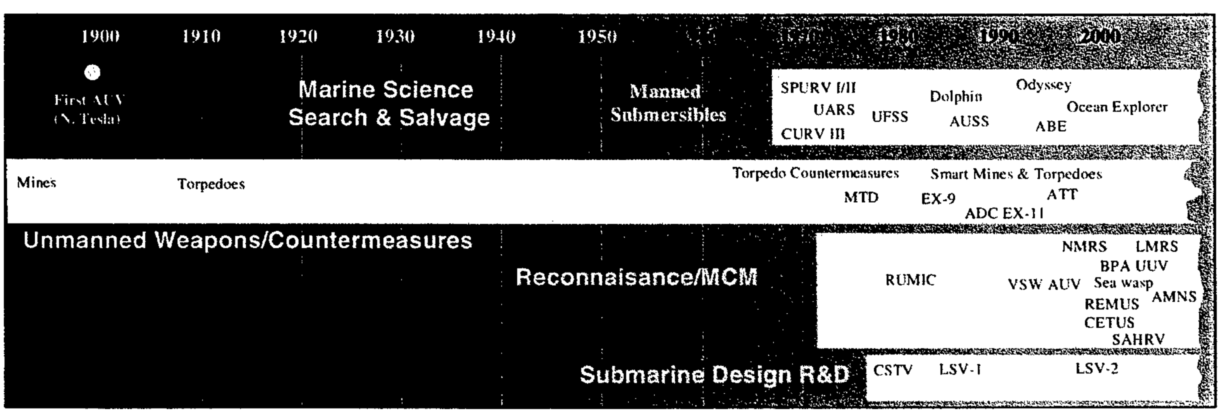


FIGURE 3-2. OVERVIEW OF UNMANNED UNDERSEA VEHICLE (UUV) HISTORY AND EVOLUTION

Remotely-operated vehicles (ROVs) were initially developed and used for search and salvage operations in the late 1960s. Notable among these early efforts was the Navy's torpedo recovery ROV called CURV III, which recovered a lost hydrogen bomb following the crash of a B-52 bomber off the coast of Spain. Throughout the 1970s and 1980s ROVs also became widely employed in the offshore oil and gas exploration industry, to the point where their use is now "commonplace and widely accepted".[18]

Navy interest in autonomous undersea vehicles (AUVs) grew in the late 1960s and early 1970s initially to support oceanographic data collection for anti-submarine warfare. The first autonomous UUVs developed for this mission, Self-Propelled Underwater Research Vehicle and Unmanned Arctic Research Vehicle, were successful enough to stimulate further development for expanded missions, with DOD continuing to play the major role in U.S. autonomous vehicle R&D throughout the 1970s and 1980s. One notable example from this period is the Advanced Unmanned Search System, fielded by the Naval Ocean Systems Center (now SPAWAR-SD). In contrast, the AUV R&D programs in most other countries were focused more on civilian and scientific research during this timeframe.[18]

AUV development within DOD accelerated in the 1990s principally to address cable laying for economic reasons and more importantly, to offer an unmanned solution for the dangerous and time-consuming tasks associated with mine countermeasures.[18]

DARPA and the Navy had undertaken the development of several AUV test-bed vehicles equipped with a variety of payloads geared toward various missions. On the mine countermeasures (MCM) side, development led to the Submarine Offboard Mine Search System (SOMSS), which was cancelled in the mid-1990s after Congressional review and subsequent establishment by the Navy of a UUV Master Plan. The plan laid out the following four priorities:[21]

- **Priority 1**: Develop an initial capability for clandestine mine reconnaissance designated the Near-Term Mine Reconnaissance System (NMRS). This minehunting UUV, launched and controlled by umbilical cord from a 688-class attack submarine, reached initial operational capability (IOC) in 1999.
- **Priority 2**: Develop the Long-Term Mine Reconnaissance and Avoidance System (LMRS), which would build on the technologies and lessons-learned from NMRS and SOMSS to provide a fully autonomous, significantly improved and more robust, clandestine, minefield avoidance and reconnaissance system. Originally intended to be launched from both submarines and surface ships, the LMRS was later designed for submarine launch only. LMRS is currently in development, with a planned IOC in 2003. The organic mine reconnaissance and avoidance requirement for surface ships is being addressed by the Remote Minehunting System (RMS), which is discussed in the subsection on USVs.
- **Priority 3**: Address intelligence, surveillance, and reconnaissance missions in littoral waters, as well as tactical oceanographic measurements in politically sensitive or denied areas. This priority is currently in the concept studies phase.
- **Priority 4**: Focus on future concepts, including extension of the undersea battlespace with autonomous vehicles equipped with advanced sensors and (potentially) weapons. Current activities are focused on research and development in critical technologies

such as energy storage and conversion, propulsion, sensors, signal processing, communications, precision navigation, autonomous control, and signature reduction.

Today, the Navy's Office of Naval Research (ONR) has a number of ongoing research and development efforts focused on expanded use of autonomous UUVs, both in their organic mine countermeasures future naval capabilities (FNC) thrust as well as their autonomous operations FNC. Current ONR-funded UUV technologies for MCM, which represent some of the most advanced autonomous undersea technologies in development today, include the following:[22]

- **Battlespace Preparation AUV** – an autonomous UUV volume survey vehicle for minehunting
- **CETUS-II** – an autonomous UUV for the search and evaluation/identification of mines and other ordnance
- **DRAKE** – a modular, reconfigurable autonomous UUV for coastal sampling and undersea survey
- **MORPHEUS** – a modular, reconfigurable autonomous UUV for mine detection in shallow water
- **Surveillance and Hydrographic Reconnaissance Vehicle (SAHRV)** – an autonomous UUV for littoral reconnaissance

These UUVs, along with a number of sophisticated special sensor payloads also being developed by ONR, have been initially tested and demonstrated in a realistic mission environment during Fleet Battle Experiment Hotel, a naval exercise focused on mine countermeasure technologies that was conducted at the Joint Gulf Range Complex near Panama City, Florida, in August 2001.

As DOD UUV programs are starting to transition from development to operational status, commercial and academic development is proceeding at a more aggressive pace that will lead to dramatically increased commercial application of autonomous UUVs. Sales to industry could be up to 30 units by 2004, with a projected, cumulative total operating revenue for offshore survey exceeding $200 million and eventually developing into a billion-dollar AUV market.[23]

3.4 UNMANNED SURFACE VEHICLES

World War II saw the first experimentation with USVs (Figure 3-3). The Canadians developed the COMOX torpedo concept in 1944 as a pre-Normandy invasion USV designed to lay smoke during the invasion – as a substitute for aircraft. COMOX was designated a torpedo because it could only be programmed to traverse a fixed course. Although COMOX was not deployed, a vehicle was constructed and a successful test completed. Meanwhile, the U.S. Navy developed and demonstrated several types of "Demolition Rocket Craft" intended for mine and obstacle clearance in the surf zone. The "Porcupine", "Bob-Sled", and "Woofus 120" were variants of converted landing craft that carried numbers of mine-clearing rockets in different configurations. Unmanned operation was part of the concept, although it is unknown which, if any, of these vehicles were demonstrated as USVs.

Post-war applications of USVs expanded with the Navy using drone boats to collect radioactive water samples after atomic bomb blasts Able and Baker on Bikini Atoll in 1946. The

1950s-era U.S. Navy Mine Defense Laboratory's project DRONE constructed and tested a remotely operated minesweeping boat in 1954. By the 1960s, the Navy was using target drone boats based on remote-controlled "aviation rescue" boats for missile firing practice, and the Ryan Firefish target drone boat was used for destroyer gunnery training. Similar to UAVs, target drone USV development and use has continued and evolved over the years. Today, the Navy operates a number of USVs as target drones, including the mobile ship target, the QST-33 and QST-35/35A SEPTAR Targets, and the High Speed Maneuverable Seaborne Target.

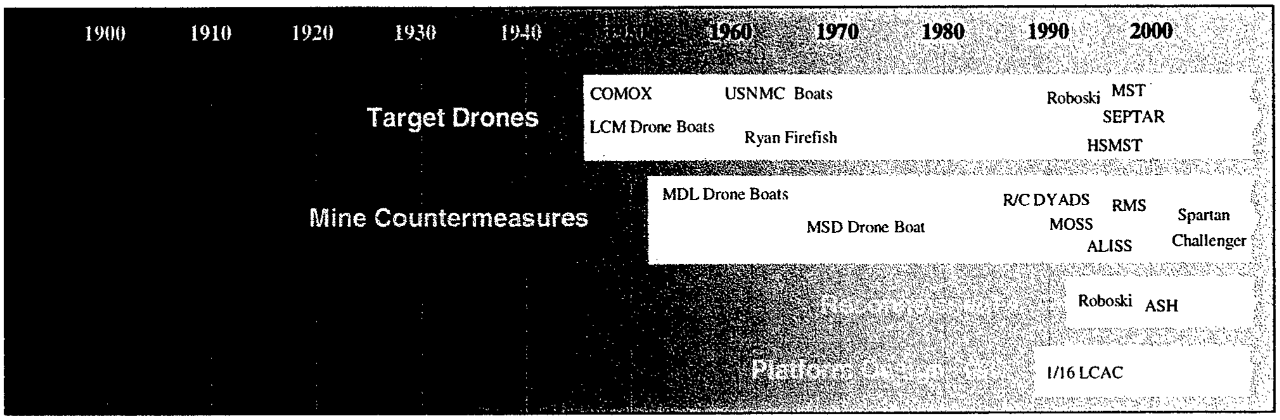


FIGURE 3-3. OVERVIEW OF UNMANNED SURFACE VEHICLE (USV) HISTORY AND EVOLUTION

Interest in USVs as minesweeping drones and for other dangerous missions continued to grow after the 1950s. Further U.S. Navy development included the small "Drone Boat", a 15-ft USV for unmanned munitions deployment that was quickly developed and deployed to the fleet as ten vehicle kits in 1965 during the Vietnam War. Larger minesweeping drone USVs were also developed and deployed in Vietnam in the late 1960s. The value of unmanned minesweeping systems was recognized by a number of countries, and systems were developed and deployed. Examples from allied countries include Denmark's STANFLEX, Germany's Troika Groups (a manned control ship operating three drones), Netherlands drones, the UK's RIM drones, Sweden's SAM II ACV drones, and Japan's SAM ACV drones operated from Hatsushima Class MCM ships.

By the 1990s, the Navy developed and tested more sophisticated USV mine sweeping systems, including the R/C DYADS, the MOSS, and finally the Advanced Lightweight Influence Sweep System, which demonstrated a remotely operated simultaneous acoustic and magnetic influence sweep capability. The most advanced and capable minehunting USV now in operation by the Navy is the Remote Minehunting System (RMS). The RMS is an air-breathing semi-submersible that tows minehunting sensors and is deployed and operated organically from surface combatants. RMS, a descendant of an earlier Canadian remotely operated minehunting vehicle called the Dolphin, can be considered one of the first examples of autonomous USVs.

Navy interest in USVs for reconnaissance and surveillance missions emerged in the 1990s with the development and deployment of the Autonomous Search and Hydrographic Vehicle and the Roboski, initially as a jet-ski type target for ship self-defense training and now also as a reconnaissance vehicle testbed. Today, several concepts for stealthy USV sensor platforms have been proposed and are under consideration by the surface fleet. One of the most

visible interests is in USVs that could serve as unmanned "pickets" to protect surface ships against small, fast boat threats and against anti-ship cruise missile threats. One of the latest emergent developments is the initiation of the Coastal Area Protection System (CAPS) ACTD by DOD. CAPS is focused on the near-term incorporation of available technologies into a system to help protect combatants in port or near coastal waters from threats such as that evidenced in the recent *USS Cole* attack. One of the principal technology features of CAPS is the modification of currently deployed 7- or 11-m rigid hull inflatable boats into remote-controlled USVs equipped with a number of sensors and other protective features.

USV development has proceeded largely in the shadows of the other unmanned programs. No coordinating organization or master plan exists within the services, and deployed air-breathing semi-submersible systems such as the early Dolphin and current RMS are usually listed under the UUV heading. If fact, even some obvious USVs, such as the Canadian Barracuda target drone and the OWL Mk II surveillance USV, are identified under the general heading of UUVs in most of the authoritative unmanned systems references.[18]

3.5 UNMANNED GROUND VEHICLES

The first notable R&D UGV testbed, as shown in Figure 3-4, was the Shakey wheeled indoor platform developed by the Stanford Research Institute for DARPA in the late 1960s. The system was operated remotely via radio frequency (RF) link by a mainframe computer. Shakey explored fundamental artificial intelligence concepts in a limited laboratory environment, but never achieved autonomous operation. Subsequent academic research by Hans Moravec led to the Stanford Cart project during the 1973 to 1981 timeframe. This project did demonstrate autonomous navigation and obstacle avoidance in a well-defined and constrained laboratory environment. However, computer technology of the times again predicated offboard control by a mainframe computer. Moravec's work later evolved into the Carnegie Mellon University's Rover indoor platform, which led to the NAVLAB vehicles that represented a foundation in mobile robot research.[18]

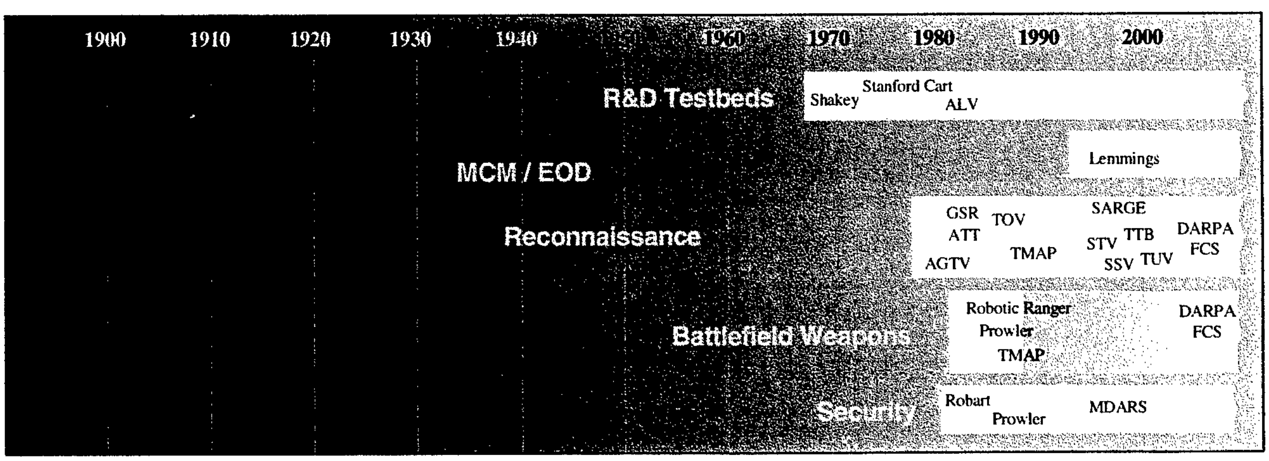


FIGURE 3-4. OVERVIEW OF UNMANNED GROUND VEHICLE (UGV) HISTORY AND EVOLUTION

DOD-related UGV research moved into the outdoors with the development of DARPA's Autonomous Land Vehicle (ALV) in the early 1980s. Road-following demonstrations with obstacle avoidance as well as off-road transit were demonstrated in 1985 through 1987. However, in 1988 the ALV program was refocused from military applications toward off-road navigation science and technology investigations. Autonomous navigation techniques developed for ALV were adapted into the Joint Army/DARPA Advanced Ground Vehicle Technology Program, which developed two concept vehicles that were demonstrated in 1987.[18]

Meanwhile, during the early 1980s the Navy and Marine Corps started developing UGVs oriented toward reconnaissance, surveillance, and target acquisition (RSTA). The Ground Surveillance Robot was an autonomous vehicle based around a fully-actuated M-114 armored personnel carrier. It was successfully demonstrated in 1986 at which time funding ran out. The Advanced Teleoperator Technology vehicle was a remotely operated dune buggy that successfully demonstrated teleoperation for transiting complex terrain and remote operation of vehicle-mounted weapons systems.[18]

The success of these two vehicles led to the initiation of the Ground/Air Telerobotic Systems (GATORS) Program in 1985. GATORS developed a Teleoperated Vehicle T&E testbed based on a High Mobility Multi Purpose Wheeled Vehicle. Successful demonstration of this vehicle in 1988 included high-speed cross-country transit, long-range RSTA, chemical-agent detection, and remote-controlled firing of a 50-caliber machine gun.[18]

Battlefield use of robotic systems was also being explored by the Army Missile Command in the early 1980s. A successive series of robotic anti-armor weapons platforms were developed and demonstrated – including the Grumman Robotic Ranger, the RDS Prowler, and a number of systems produced by the newly-formed Teleoperated Mobile Anti-Armor Platform (TMAP) Program. However, TMAP was refocused away from weapons and towards RSTA missions after Congress prohibited robotic weapons in 1987. This is reflected in the fading out of the battlefield weapons timeline in Figure 3-4.[18] Fading back in beyond today is intended to reflect the advent of the Army and DARPA's Future Combat Systems Program, which will draw heavily on unmanned systems to produce a new lethal, lightweight, mobile, and survivable land force for the future.[24]

The DOD established the UGV/Systems Joint Project Office in 1990 in response to Congressional direction. The mission of the JPO was, and continues to be, to serve as the central focus for development and fielding of all DOD UGV systems.[18] The first program initiated by the JPO was the Tactical Unmanned Ground Vehicle, a joint Army and Marine Corps effort that provided the foundation for the Army's incorporation of unmanned systems into the vision for future forces.[24]

Under the JPO, the 1990s saw the introduction of a number of UGV systems, as outlined in the FY2000 Joint Robotics Program Master Plan.[25] Some, such as the Standardized Robotic System (SRS), produced teleoperation kits that can be retrofitted to a variety of military vehicles, some of which are deployed in Bosnia today.

The key UGV projects highlighted in the FY2000 Master Plan include the following:[25]

- **Vehicle Teleoperation (VT)** – Produces the SRS kits that provide standardized remote control or semi-autonomous control to military vehicles. A key example is the Panther – a turret-less M-60 Tank equipped with mineproofing rollers.

- **Robotic Combat Support System** – Rapidly deployable robotic system for anti-personnel mine neutralization.
- **Family of Tactical Unmanned (Ground) Vehicles** – A thrust oriented towards assisting services in defining and refining requirements for a family of UGVs across a spectrum of sizes, configurations, and payloads.
- **Basic Unexploded Ordnance Gathering System** – A UGV system to locate and dispose of surface unexploded ordnance (UXO) for EOD.
- **Robotic Ordnance Clearance Systems (ROCS)** – Development of robotic EOD systems for surface and buried UXO detection/ID/removal/disposal.
- **Mobile Detection Assessment Response System** – Robotic vehicles for semi-autonomous security patrol and surveillance in both interior and exterior environments.
- **UGV Technology Enhancement and Exploitation Program (Demo III)** – A program designed to mature and demonstrate technologies to be incorporated into UGV systems.
- **Joint Architecture for Unmanned Ground Systems** – Development of a common software architecture focused on UGV interoperability and affordability.

The Navy is also developing technologies for UGVs under ONR's autonomous operations FNC focused on mine countermeasures and amphibious warfare. One UGV system currently under development and testing by the Navy is a family of tracked lemming vehicles that operate in the surf zone and on the beach, initially for mine countermeasures, but potentially for RSTA missions as well.

3.6 THE STATE OF UNMANNED SYSTEMS TODAY

A very large number of unmanned systems are available today, both commercially and for the military. Figure 3-5 provides a representative, albeit not complete overview, which illustrates that UAVs still dominate, but UUVs and UGVs are catching up especially in the commercial sector.[18] Although USVs predate UGVs, they have not received much visibility and, as previously mentioned, currently lack a DOD master plan.

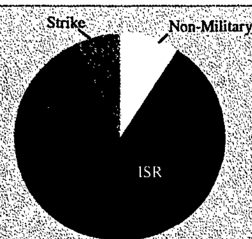
The continued growth of unmanned systems within DOD and large numbers of available systems reflect the fact that these technologies are now maturing to the point where tactical (and strategic) military utility has been demonstrated. The next evolution will shift from an emphasis on performance to an emphasis on affordability and deployability as larger numbers of systems are considered for full-scale military applications. However, as illustrated in Figure 3-6, most unmanned systems today generally reflect point designs with little or no standardization or modularity across a specific type of vehicle and even less so across different vehicle types. Affordable acquisition of very large numbers of systems and deployability with the fleet in large numbers will require a sea change in modularity and standardization, as discussed in Section 2.0.

This is not to say that nothing is happening today to move towards standards and modularity. Figure 3-7 provides examples of master plans, coordinated programs, and products that represent initial steps toward standardization. Figure 3-8 highlights a few of the products listed in Figure 3-7, including standardized control systems, containers, and launch and recovery

techniques. The Tactical Control System (TCS) (Figure 3-8, Detail A) is being developed as standard ground-control station architecture for DOD UAVs by PEO(W).[26] Additionally, CSS has successfully demonstrated control of a Roboski USV with TCS. CSS has also developed a Windows-NT based standard UUV control system for oceanographic research projects.[27] The Boeing UCAV (Figure 3-8, Detail B) is designed to be stowed in a humidity-controlled storage/shipping container for up to ten years.[28] The Hugin 3000 autonomous UUV (Figure 3-8, Detail C) is shipped and launched from a standard ISO container. Although the Hugin is a commercial UUV, early DARPA UUV testbeds were launched and recovered from ISO containers in 1990 sea tests in Dabob Bay, Washington State.

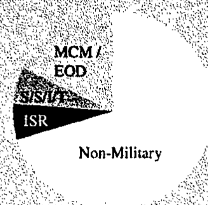
UAV

APPLICATION	FIX WING	VT/HELO	A-STAT	TOTAL
Non-Military	11	0	0	11
Military - ISR	68	8	1	77
Military - Target	24	0	0	24
Military - Precision Strike	8	0	0	8
TOTAL	111	8	1	120



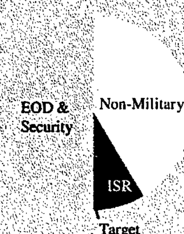
UUV

APPLICATION	ROV	AUTONOMOUS	TOTAL
Non-Military	42	5	47
Military - ISR	3	1	4
Military - Sch/Slvg/Insp/Tgt	2	2	4
Military - MCM / EOD	8	9	17
TOTAL	55	17	72



UGV

APPLICATION	INDOOR	OUTDOOR	EITHER	TOTAL
Non-Military	9	7	7	23
Military - ISR	0	4	0	4
Military - Target	0	1	0	1
Military - EOD & Security	1	12	3	28
TOTAL	10	24	10	56



USV

APPLICATION	ROV	AUTONOMOUS	TOTAL
Non-Military	0	0	0
Military - ISR/Ship Def	3	0	3
Military - Target	5	0	5
Military - MCM / EOD	1	1	2
TOTAL	9	1	10

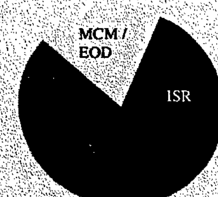


FIGURE 3-5. OVERVIEW OF UNMANNED VEHICLES ON THE MARKET TODAY

Clearly, standardization and modularity are starting to appear in unmanned systems designs. At the incremental level, additional progress will be made by the establishment of a USV master plan and by further development of the pieces of the puzzle shown in Figure 3-7.

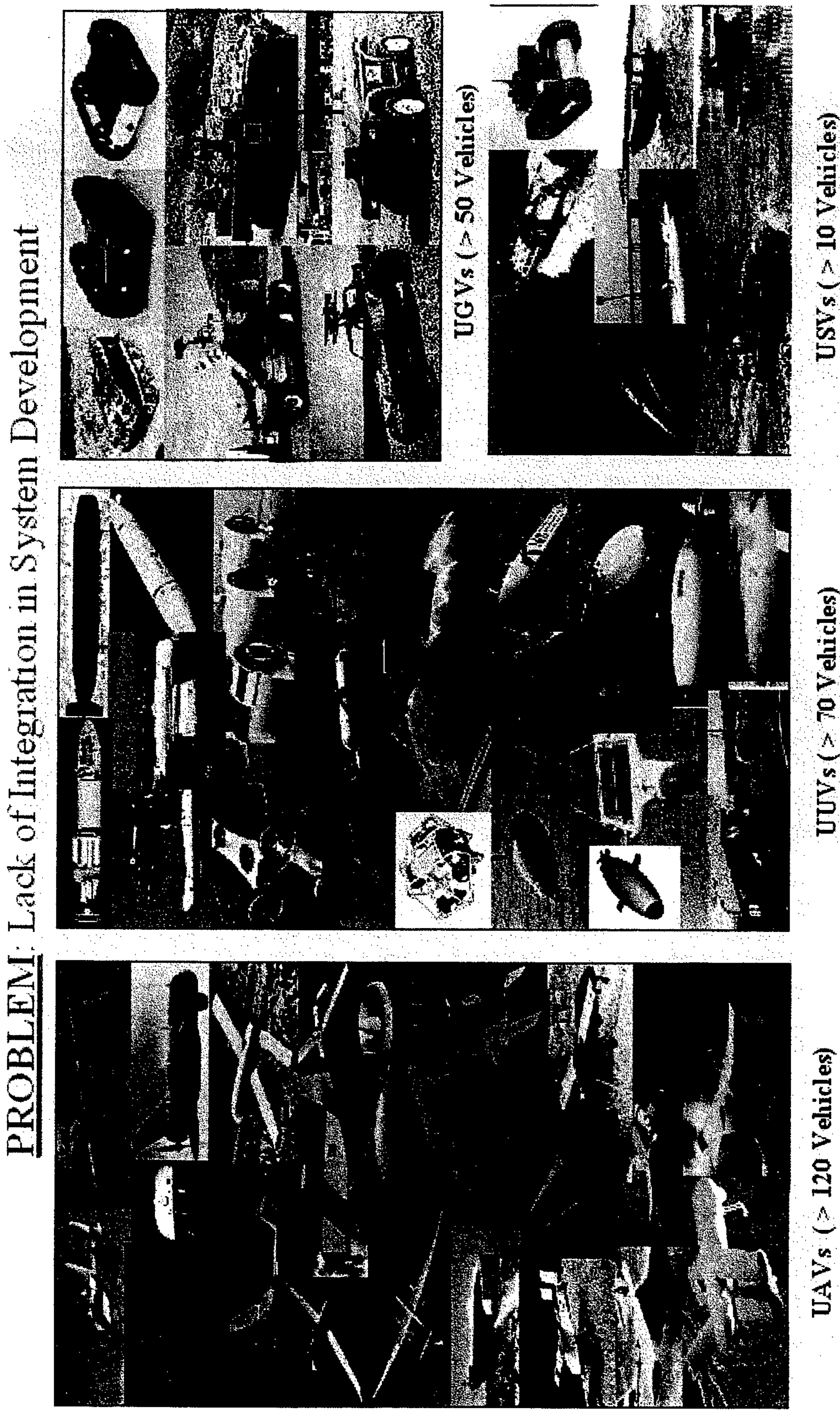


FIGURE 3-6. UNMANNED SYSTEMS TECHNOLOGY - CIRCA 2001

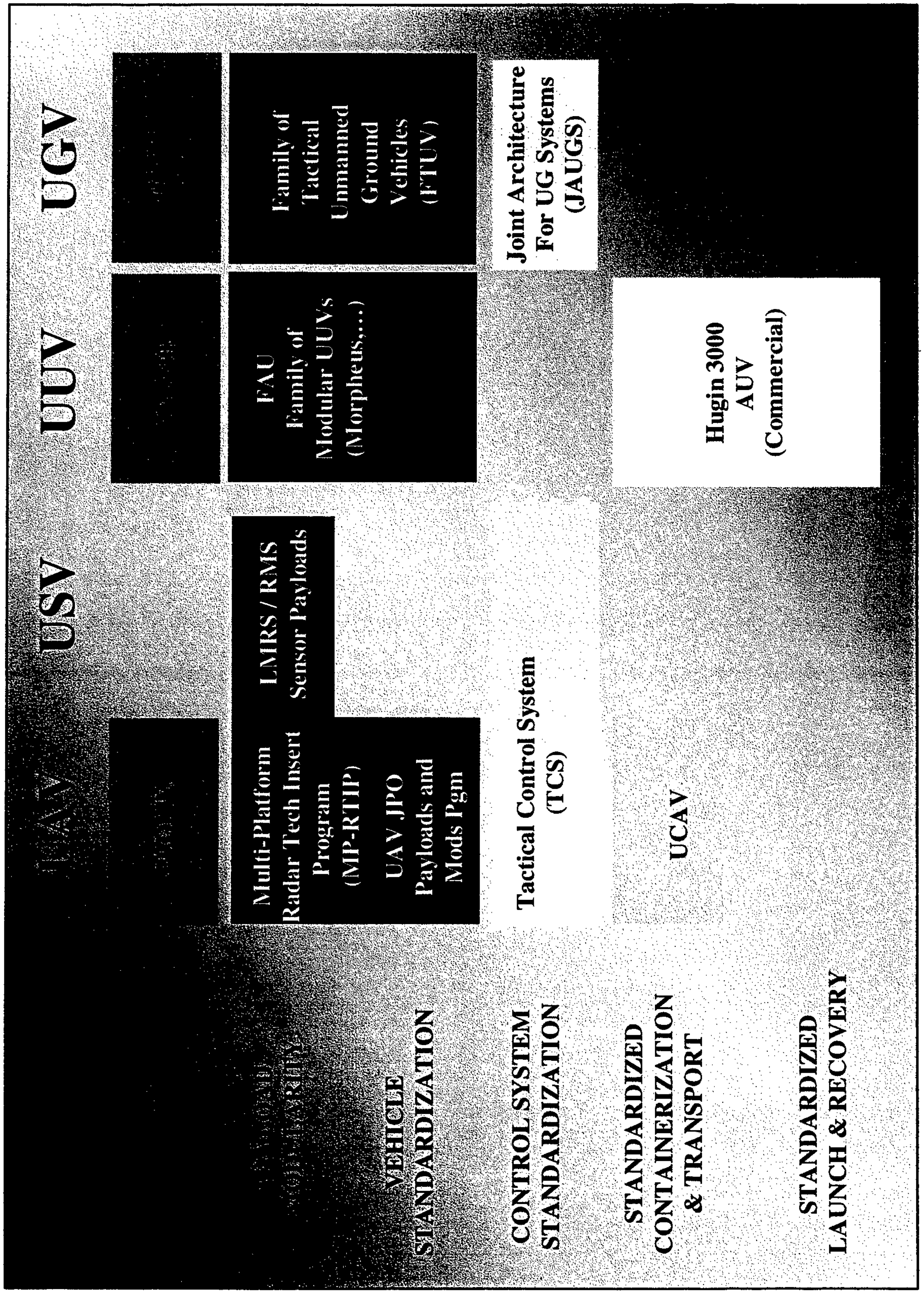


FIGURE 3-7. SOME EXAMPLE STEPS TOWARD STANDARDIZATION AND MODULARITY IN UNMANNED SYSTEMS

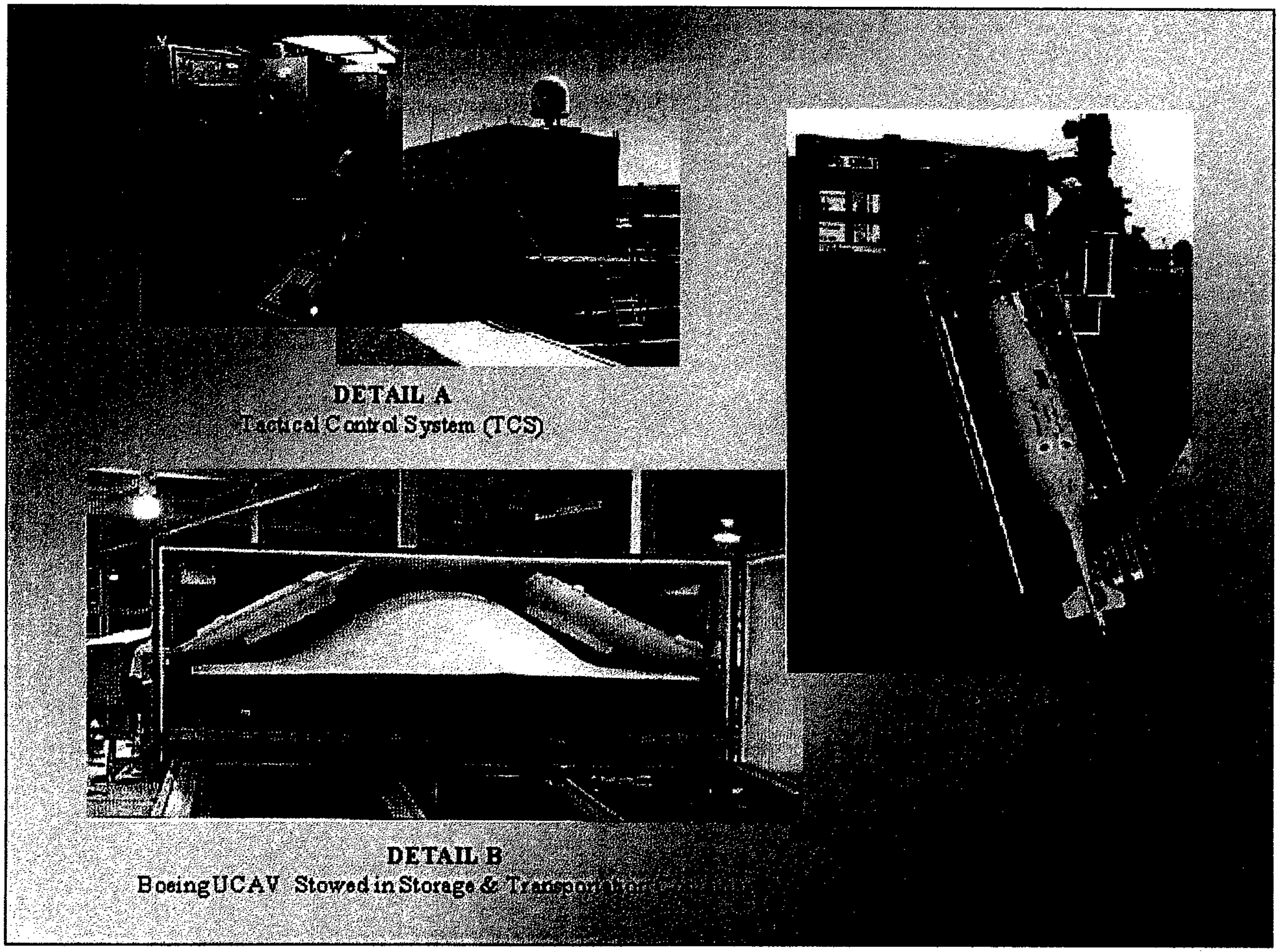


FIGURE 3-8. EXAMPLES OF CONTAINERIZATION AND L&R IN UNMANNED SYSTEMS

However, on a grander scale, eventual acquisition and deployment of potentially large fleets of unmanned systems requires a systems engineering approach to fully apply standards and modularity across the full unmanned systems spectrum (Figure 3-7), at least within the boundary conditions imposed by physics and engineering realities.

It is our contention that unmanned systems will inevitably grow into a dominant augmenting arm of our naval forces. The challenge for the future is to lay out a path that takes us from relatively disparate and fragmented development of multitudes of "custom" systems to development of an affordable and deployable "family" of unmanned systems that address the full spectrum of applicable naval mission requirements and take advantage of the economies of scale. Towards this objective, CSS pursued the unmanned systems Concept Development Study that is described in Section 4.0.

SECTION 4.0 UNMANNED SYSTEMS CONCEPT DEVELOPMENT STUDY

4.1 OBJECTIVE AND METHODOLOGY

The concept development study was conducted to:

- Identify the largest set of Navy missions that could be satisfied by the smallest number of unmanned systems components
- Define a common unmanned systems functional architecture
- Produce example conceptual designs that would demonstrate what the physical components might look like

The study proceeded in a top-down manner that focused on finding commonalities across the requirements. By focusing on the common requirements and identifying missions suitable for unmanned systems, a set of building blocks was defined. This small number of blocks was grouped in various ways to satisfy a wide range of Navy mission requirements.

The study required examination of a large number of Navy missions. To keep this problem tractable, the study team adopted a systems engineering (SE) methodology. The SE method is a structured approach of system development that produces a balanced solution to meet the requirements of the problem at hand. Many references describe various realizations of the SE process.[29,30,31] Generally, the process can be described in terms of three major steps:

- **Requirements Analysis.** This step identifies and verifies the top-level requirements that the system must satisfy, and the constraints for system development. From these, a set of derived requirements may also be defined. Together, these comprise a set of originating requirements for system design.
- **Functional Architecture Development.** Here, the functions that the system must perform (i.e., what must be done and why) are defined and verified. Each function is traced back to one or more originating requirements. The functions are then organized to produce an architecture that describes what the system must do. The architecture consists of groupings of functions in a hierarchical manner. Since there are many alternative groupings, some guidance or principles must be provided to select the desired configuration.
- **Design Synthesis.** In this stage, the elements of the functional architecture are allocated to the physical components of the system. The resulting architecture is then verified to ensure that it meets the original requirements. It is at this step that how the functions are performed is finally defined. Again, there are many alternatives. Design guidance beyond the originating requirements is needed to select the optimal design.

Since the study was intended to define functional requirements, most of the effort was focused on the first two steps of the SE process. The development of a final physical architecture is not possible at this time because it requires the establishment of operational

requirements (derived, for instance, from threat analyses) and definition of detailed design guidance, which are beyond the scope of this effort.

The outcome of this process is the definition of a functional architecture for unmanned systems that allows performance of many Navy missions across all major warfare areas. The architecture emphasizes the use of common components and standards to enable a single platform to perform multiple tasks, and the reuse of a limited set of components for many applications. Such a functional description can be used to guide the Navy research efforts by identifying the technologies that must be developed to enable the unmanned systems concept.

4.2 ASSUMPTIONS AND CONSTRAINTS

The paragraphs that follow present in detail the assumptions and constraints that guided the development of the unmanned systems concept.

4.2.1 Time Frame

The study selected the year 2030 as the target for a fully operational system. This date is consistent with the warfare systems development cycle experienced in recent years:

Research and Technology Development	10 - 15 years
Acquisition (Initial Operational Capability)	10 - 15 years
Production (Full Fleet Capability)	5 - 10 years
TOTAL	25 - 40 years

Based on these estimates, the study assumed that development of unmanned systems would take about 30 years from basic research to operational capability. Therefore, the year 2030 was selected as the approximate date when the full capabilities of the unmanned systems architecture would be available if the development effort were started today. However, the assumed technology basis is the year 2015. This means that the concept was developed assuming the state of technology that will exist in about 15 years. The future technology assessments are based mainly on projections made by the Naval Studies Board.[32] These projections were supplemented with the assessments from CSS technical experts, especially in the area of underwater acoustics.

4.2.2 The Role of Unmanned Systems in the Navy

The spectrum of ways in which unmanned systems can be used runs from increasingly automated systems that reduce operator workload, to fully autonomous systems capable of performing entire missions without human intervention. The selection of the proper point on the spectrum for Navy systems involves considerations beyond what is operationally and technically feasible, and into the realm of moral and ethical issues.

The concept presented here is based on a vision of unmanned systems used to augment Navy capabilities, rather than to replace people or platforms. Such a vision favors the use of small (relative to the combatants), remotely operated platforms with limited local autonomy and human supervision. For instance, a group of unmanned surface crafts is tasked by an operator to perform a particular mission. During the mission, the vehicles operate themselves according to

the mission plan, thus avoiding the need to have one operator for each vessel (this represents limited local autonomy). The vehicles report mission status via a command and control link. If necessary, the operator can revise the plan, issue a new mission plan, or cancel the mission. The use of limited automation in this fashion serves as a force multiplier by allowing one operator to perform a task that would normally require several persons.

The vision of unmanned systems used to augment Navy capabilities is motivated by several considerations:

- The U.S. Navy will face uncertain threats in the 21st Century. The existing naval force may or may not be adequate in the future, but it is a force whose capabilities and limitations are well understood. It would be unwise to introduce a radically new force structure in the context of an uncertain threat environment. Unmanned systems must augment, not displace, the existing force structure.
- The realities of the Navy systems acquisition process make it very difficult to do the kind of major changes to an existing platform that would be needed to carry and deploy unmanned systems. However, by modifying only the manned platform's command and control infrastructure, remote control operations can be performed. If all that is required is to remotely supervise an unmanned platform, then it is plausible for any existing Navy platform (aircraft, surface vessel, or submarine) to use unmanned systems.
- The notion of allowing machines to make decisions that may cost human lives involves legal, moral, and ethical considerations. The consequences of mistakenly firing on friendly forces or civilians would be greatly magnified if a computer were allowed to make the firing decision. These problems are greatly diminished by keeping the unmanned systems under human supervision.

These arguments call for an evolutionary approach to the widespread use of unmanned systems in the Navy. In this approach, the unmanned capabilities are introduced gradually while minimizing the impact on the existing manned force, thus preserving the current capabilities until the strengths and limitations of the unmanned technology are understood. Moreover, the use of remotely supervised unmanned systems enables an operator to have the final decision authority on what the unmanned system may or may not do. This vision of the role of unmanned systems relative to the manned naval forces is the basis of the concept presented in this report.

4.2.2.1 <u>Number of Unmanned Platforms</u>. It is likely that future naval unmanned systems will comprise a large number of relatively small platforms. While it may be technically feasible to develop an unmanned system of the size of a destroyer, its cost is likely to be very significant even after accounting for the operational cost reductions due to the absence of a crew. A small platform is more likely to be affordable. However, its payload capacity, endurance, and sensor or weapon range will be limited. Therefore, multiple platforms may be needed to compensate for these limitations. Fortunately, manufacturing technology allows making multiple copies of an item while reducing the unit cost, so a large number of small, unmanned platforms may still be affordable.

Large numbers of unmanned systems have some other advantages. First, they present an enemy with multiple targets to track and prosecute. The loss of a few platforms reduces, but does not eliminate, a mission capability since the remaining units can still perform the assigned

mission. On the other hand, a large number of small platforms present a more difficult command and control problem. Furthermore, such platforms must be transported to the theater of operations. These issues will be explored as part of the concept to be presented later in the report.

4.2.2.2 Force Structure. Since the concept has the objective of augmenting, not replacing, the naval forces, the study used as a basis the programmed Navy force structure for the year 2030 as reported by the Secretary of the Navy to the U. S. Congress.[33] Table 4-1 is a summary of the projected number of major combatant platforms reported in the reference for a steady state force of 306 ships.

TABLE 4-1. PROGRAMMED NAVAL FORCES FOR THE YEAR 2030

PLATFORM	NUMBER
Aircraft Carrier	12
Combatants	116
Amphibious Ships	36
Combat Logistic Ships	32
Mine Warfare	16
Support Ships	25
Ballistic Submarines (SSBN)	14
Attack Submarines (SSN)	55
Total	306

Based on the current plans for maintaining 12 CVBGs and ARGs through the year 2030, the data from the table can be used to determine the composition of a typical CVBG/ARG of the future. Table 4-2 shows this composition. The values were derived by distributing the projected number of platforms in each category among 12 CVBGs/ARGs. While this is not the way that a battle group is organized, the method provides an idea of the number and types of ships that may be available in a future fighting unit.

TABLE 4-2. ESTIMATED COMPOSITION OF A TYPICAL BATTLE GROUP IN THE YEAR 2030

GROUP	PLATFORM	TYPICAL NUMBER
Carrier Battle Group	Aircraft Carrier	1
	Combatants	8
	Attack Submarines	4
Amphibious Ready Group	Amphibious Assault Ship (LHX)	1
	Amphibious Transport Dock (LPD17)	1
	Landing Dock Ship (LSDX)	1
Combat Logistic Force	Fast Combat Support Ship (AOE)	1
	Underway Replenishment Oiler (TAO)	1
Others	Mine Countermeasures Ship (MCM(X))	1
Typical Number of Ships in a CVBG/ARG		19

Table 4-1 shows that many of the platforms that exist today are expected to still be in service in the year 2030. These platforms were designed based on present operational requirements. It is unlikely that they will be easily modified to support unmanned systems since their current operational requirements are unlikely to be appreciably changed. Plans for newer platform designs (like DD21) do provide support for unmanned systems like RMS and Fire Scout. However, they cannot store or service a large number of these. Aircraft carriers could support unmanned air platforms, but they are not likely to support surface and underwater vehicles without significant structural modifications and vulnerability trade-offs. Some amphibious ships could support a wide variety of unmanned platforms, however, not simultaneously while supporting their existing Marine Corps requirements. The logistics ships have space where unmanned systems could be carried, but this space is occupied by the combat stores that support the battle group.

The data in the tables leads to the conclusion that the programmed force for the year 2030 is very unlikely to be able to support large numbers of unmanned off-board platforms. Any concept for introducing unmanned systems into the fleet must consider how these systems will be brought to, and sustained in, the theater of operations. At the same time, the concept must allow the operational control of the unmanned assets to remain with the manned platforms.

4.3 CONCEPT DEVELOPMENT PROCESS

Figure 4-1 shows an overview of the concept development process. Following the SE methodology, the process begins with a requirements analysis to define the set of originating requirements for the unmanned systems concept. A functional decomposition and allocation follows. The result is a functional description of what the elements of the unmanned system must do. Each element can be traced back to the originating requirement. The paragraphs that follow describe the process and the products in detail.

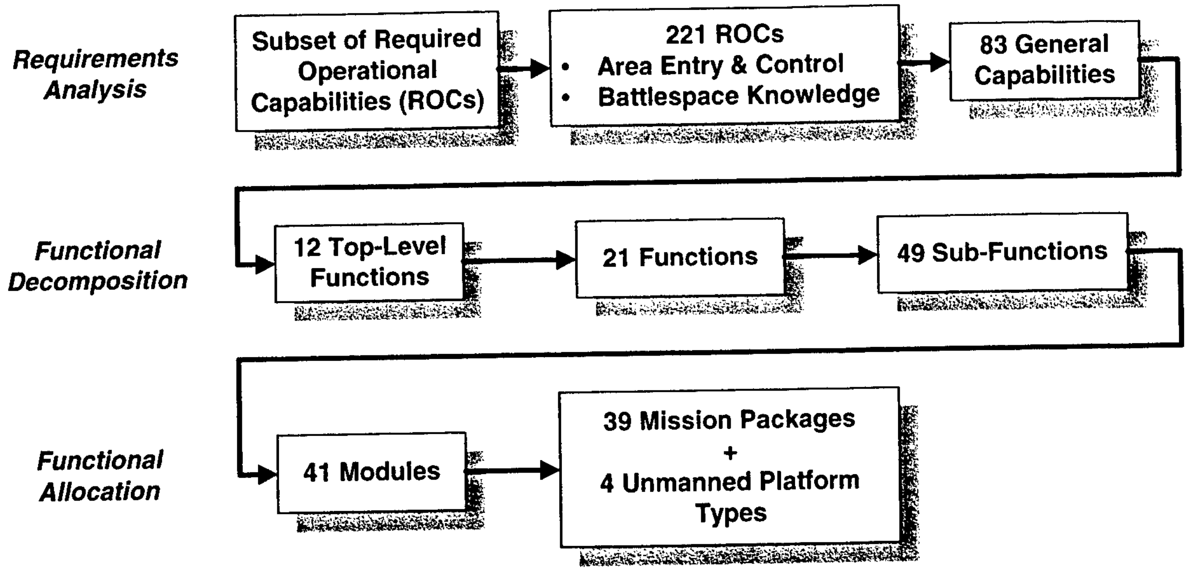


FIGURE 4-1. OVERVIEW OF THE SYSTEMS ENGINEERING PROCESS FOR CONCEPT DEVELOPMENT

4.3.1 Requirements Analysis

The top-level requirements were selected from a large set of naval required operational capabilities (ROCs). From this set, a subset of capabilities relevant to unmanned systems was identified based on the following criteria:

- **Warfighting and Forward Presence**. The study considered only capabilities related to these two aforementioned operations. Operations other than war, peacetime operations, naval construction, and strategic sealift warfare areas were not considered.
- **Warfighting Functions**. Only the warfighting functions of area entry and control, and battle space knowledge were considered. The power projection function was excluded because of limitations in the resources available for the study. This decision excluded the strike warfare area. However, this should not be interpreted as implying that unmanned systems cannot contribute to this important function, because they already do.
- **Year 2015 Technology**. As stated earlier, the study is based on the technology basis of the year 2015. The selection of capabilities was made considering whether the relevant technology would be mature enough to fulfill the requirements using unmanned systems by 2015.
- **Human Skills**. The selection process excluded capabilities that are heavily dependent on human skills like judgment, intuition, and experience, or mechanical skills like hand-eye coordination. Capabilities like the ability to plan missions and command and control decision-making were excluded since the unmanned systems concept is based on human oversight and supervision.
- **Dirty, Dull, or Dangerous**. The study favored tasks that may be considered dirty, dull, or dangerous. Minesweeping is a good example of such tasks. Clearly, having unmanned systems that can contribute to these tasks is very desirable.

The selection process reduced the original capability statements to a subset of 221 items in which unmanned systems could play a role. Because of some overlaps and redundancies, these 221 statements were consolidated into 83 general ROC statements that served as top-level requirements for unmanned systems concept development. It is important to note that the consolidated ROC statements relate to some of the most important missions that the Navy must perform. Therefore, any unmanned system that supports these ROCs will provide an important contribution to Navy capabilities.

4.3.2 Functional Decomposition

The selection and decomposition of the functions was based on a general understanding of the warfare functions underlying each top-level requirement. Accordingly, the decomposition is to some extent subjective. The 83 ROCs were allocated to one of 12 top-level functions. These functions translate the ROCs into a more general construction in order to identify commonalities among the requirements. The top-level functions are broken into 21 functions and 49 sub-functions as shown in Table 4-3. The following observations are helpful in understanding the contents of this table:

- In the table, the term "surveillance and warning" is used to denote object sensing over relatively large areas, possibly at lower resolution. In contrast, "reconnaissance and targeting" denotes object sensing or tracking over a relatively small area, probably at higher resolution, as it is often needed for target acquisition or identification.
- The system's functional architecture links with the physical architecture at the sub-function level. Accordingly, some sub-functions reflect the physical possibilities and limitations of the system components to be developed. For example, the function "Sense Targets, R-T" (target sensing for reconnaissance and targeting purposes) is broken into three "Recon-Targeting" sub-functions: (1) Acoustics (sensing via underwater acoustic signals); (2) air and surface (sensing via radio frequency, infrared, or optical means); and (3) Magnetics (sensing via magnetic signals). These reflect the most common physical means by which the sensing can be done.
- The term "Provide info to C^2" denotes communication functions. The sub-functions identify variations of this function according to the physical signal propagation phenomenon (e.g. acoustic, magnetic, or electromagnetic). The decomposition adopted the view that the communication functions are basic signal transmission and reception functions. The signal may be information, or jamming and deception signals. According to this view, the top-level "Jammer" function doesn't require a reception or transmission function. Instead, the function is implemented by interfacing the jamming function with one of the "Provide info to C^2" communication sub-functions.

In Table 4-3, it is important to note that as the decomposition progresses some common sub-functions start to appear. For example, the sub-function "Store Information" appears often. Such a function points to an opportunity for developing a common device that can support many applications (in this example, data storage).

TABLE 4-3. FUNCTIONAL DECOMPOSITION

TOP-LEVEL FUNCTION	FUNCTION	SUB-FUNCTION
Acquire C^3, Weapon, WARM Signals	Alert C^2	Provide info to C^2, acoustics
		Provide info to C^2, magnetics
		Provide info to C^2, RF-EO
	Sense enemy signals	Interface Signal Interceptor to Comms
		Store information
	Sense WARM	Process signal to determine WARM
Acquire Environmental Data	Alert C^2	Provide info to C^2, acoustics
		Provide info to C^2, magnetics
		Provide info to C^2, RF-EO
	Conduct positioning	Hold station
		Maneuver to mission area
	Search area	Execute search pattern
	Sense environment	Gather MET data
		Gather ocean data
		Store information
Comms Relay	Alert C^2	Provide info to C^2, acoustics
		Provide info to C^2, magnetics
		Provide info to C^2, RF-EO
	Conduct positioning	Hold station
		Maneuver to mission area
	Re-broadcast friendly signals	Execute relay pattern
		Install cable
		Relay Translator
		Store information
Deception	Conduct positioning	Hold station
		Maneuver to mission area
	Deceive enemy signals	Alter appearance
		Deceive magnetic sensors
		Deception-Comms Interface
		Maneuver to deceive
	Sense enemy signals	Interface Signal Interceptor to Comms
		Store information
Deliver Weapon	Engage targets	Employ directed energy munitions
		Employ kinetic energy munitions
		Employ NLW munitions
		Employ warhead munitions
		Maneuver to intercept target
	Sense targets, R-T	Recon,Targeting, acoustic
		Recon,Targeting, air and surface
		Recon,Targeting, magnetic

TABLE 4-3. FUNCTIONAL DECOMPOSITION (CONTINUED)

TOP-LEVEL FUNCTION	FUNCTION	SUB-FUNCTION
Deliver, Extract, Recover Objects	Conduct positioning	Hold station
		Maneuver to mission area
	Deliver objects	Deliver air objects
		Deliver ground objects
		Deliver surface objects
		Deliver undersea objects
	Recover objects	Grasp and load air objects
		Grasp and load ground objects
		Grasp and load surface objects
		Grasp and load undersea objects
	Search area	Execute search pattern
	Sense targets, guidance	Terminal guidance, acoustic
		Terminal guidance, magnetic
		Terminal guidance, RF-EO-IR-mmW
	Sense targets, R-T	Recon,Targeting, acoustic
		Recon,Targeting, air and surface
		Recon,Targeting, magnetic
Jammer	Jam enemy signals	Interface Jammer to Comms
	Sense enemy signals	Interface Signal Interceptor to Comms
		Store information
Monitor Chem/Bio/Radiation	Alert C^2	Provide info to C^2, acoustics
		Provide info to C^2, magnetics
		Provide info to C^2, RF-EO
	Conduct positioning	Hold station
		Maneuver to mission area
	Search area	Execute search pattern
	Sense contaminants	Gather samples
		Process samples
		Sense radiation
		Store information
Nav Aid,Marker	Conduct positioning	Hold station
		Maneuver to mission area
	Emit own position	Interface Nav to Comms
	Sense own position	Track-update own position, low accuracy
		Track-update own position, med accuracy

TABLE 4-3. FUNCTIONAL DECOMPOSITION (CONTINUED)

TOP-LEVEL FUNCTION	FUNCTION	SUB-FUNCTION
Recon,Targeting, BDA	Alert C^2	Provide info to C^2, acoustics
		Provide info to C^2, magnetics
		Provide info to C^2, RF-EO
	Conduct positioning	Hold station
		Maneuver to mission area
	Search area	Execute search pattern
	Sense targets, BDA	Assess damage to target, acoustics
		Assess damage to target, air and surface
		Store information
	Sense targets, R-T	Recon,Targeting, acoustic
		Recon,Targeting, air and surface
		Recon,Targeting, magnetic
Structure Inspection	Alert C^2	Provide info to C^2, acoustics
		Provide info to C^2, magnetics
		Provide info to C^2, RF-EO
	Conduct positioning	Hold station
		Maneuver to mission area
	Search area	Execute search pattern
	Sense own signatures	Sense fields
	Sense targets, R-T	Recon,Targeting, acoustic
		Recon,Targeting, air and surface
		Recon,Targeting, magnetic
Surveillance and Warning	Alert C^2	Provide info to C^2, acoustics
		Provide info to C^2, magnetics
		Provide info to C^2, RF-EO
	Conduct positioning	Hold station
		Maneuver to mission area
	Search area	Execute search pattern
	Sense targets, surveillance	Store information
		Surveillance, acoustic
		Surveillance, RF-EO-IR-mmW

Acronyms and Abbreviations

BDA	Battle damage assessment
C^2	Command and Control
C^3	Command, Control and Communications
CBR	Chemical, biological, radiation
EO	Device based on electro-optical signals
IR	Device based on infra-red energy signals
mmW	Device based on millimeter wave signals
NLW	Non-lethal weapon
RF	Device based on radio frequency signals
R-T	Reconnaissance-Targeting

4.3.3 Functional Allocation

One of the goals of the decomposition is to ensure commonality and modularity in the design. For this reason, the functional allocation adopted the view that a common set of unmanned platforms would be used to provide as many of the top-level required capabilities as possible. With this view, the functional allocation assigned some sub-functions to the platform itself. These are the so-called "hotel" functions that provide basic mobility capabilities like maneuvering, positioning, and communications. The remaining sub-functions were allocated to modules that can be carried on board one or more of the standard platforms according to the mission being performed. This enables re-using the same unmanned platform to do multiple tasks by reconfiguring its payload.

4.3.3.1 Platform Types. The analysis assumed that there are four basic types of unmanned platforms. These can be decomposed into mobile vehicles and stationary nodes, as follows:

Mobile	**Stationary**
Unmanned Air Vehicle (UAV)	Unmanned Air Node (UAN)
Unmanned Surface Vehicle (USV)	Unmanned Surface Node (USN)
Unmanned Ground Vehicle (UGV)	Unmanned Ground Node (UGN)
Unmanned Underwater Vehicle (UUV)	Unmanned Underwater Node (UUN)

USV denotes a water surface or semi-submersible craft. UGV refers to vehicles that move on land or over the sea bottom. A UAN could be an airship or similar balloon device, while a USN is something like a buoy. For the mobile types, the allocation process assumes that these carry the navigation, guidance, control, power, propulsion, and communications components needed to fulfill the maneuvering, positioning, and communication sub-functions. Likewise, the stationary platform types are assumed to contain components like power and communications.

4.3.3.2 Modules. With "hotel" functions assumed to exist in the platform, the functional allocation process focused on allocating the remaining payload functions to physical components. Table 4-4 describes how the sub-functions were allocated to modules that represent parts of a physical component that implements some capability.

The first ten sub-functions in Table 4-4 were considered hotel functions. These capabilities were assumed to exist in the host platform and were not explored any further. The remaining 39 sub-functions were identified as being mission related. Each of these sub-functions was allocated to one or more modules. In two cases (reconnaissance and targeting, and surveillance and warning), the sub-function was allocated to various modules, each using different signal types. This recognizes that in each environment one signal type is more effective, and that it may not be feasible to develop a single device that is equally effective in generating all signal types.

4.3.3.3 Mission Packages. Many of the modules in Table 4-4 must be combined to perform a task. For instance, a missile consists of two modules: "Weapon, Warhead" and "Weapon Guidance, RF-EO-IR-mmW", carried by a UAV platform. A combination of modules is considered a mission package. Table 4-5 lists the mission packages identified through the

functional decomposition process. The grouping reduced the 41 modules to 39 mission packages, most of which contain two or more modules. Each package can be traced back to one or more originating requirements through the functional architecture.

Figure 4-2 illustrates the allocation of mission packages to top-level functions. The decomposition and allocation process revealed that the "Jammer" and "Deception" top-level functions produce a common set of mission packages. On the other hand, the "Recon, Targeting, BDA" function produced separate families of mission packages for the reconnaissance and targeting activities, and battle damage assessment.

TABLE 4-4. ALLOCATION OF SUB-FUNCTIONS TO MODULES

SUB-FUNCTION	MODULE	DESCRIPTION
Alter appearance	Hotel Functions	Signature control
Execute relay pattern		Functions needed for maneuvering and positioning (navigation, guidance, control, propulsion, power)
Execute search pattern		
Hold station		
Maneuver to deceive		
Maneuver to intercept target		
Maneuver to mission area		
Provide info to C^2, acoustics		Communications via acoustic signals
Provide info to C^2, magnetics		Communications via magnetic signals
Provide info to C^2, RF-EO		Communications via electromagnetic signals
Assess damage to target, acoustics	Battle Damage Assessment, Acoustic	BDA using acoustic signals
Assess damage to target, air and surface	Battle Damage Assessment, RF-EO-IR-mmW	BDA using electro-magnetic signals
Deceive magnetic sensors	Deception-Jam Generator, Magnetic	Device that generates magnetic-based deception or jamming signals
Deception-Comms Interface	Interface, Deception to Comms	Device that generates electromagnetic deception-jamming signals and interfaces with the "hotel" communications device
Deliver air objects	Manipulator, UAV	Object manipulator for unmanned air vehicles
Deliver ground objects	Manipulator, UGV	Object manipulator for unmanned ground vehicles
Deliver surface objects	Manipulator, USV	Object manipulator for unmanned surface vehicles
Deliver undersea objects	Manipulator, UUV	Object manipulator for unmanned underwater vehicles
Employ directed energy munition	Weapon, Direct Energy	Direct energy (e.g., laser) weapon
Employ kinetic energy munition	Weapon, Gun	Kinetic energy (e.g., bullet or shell) weapon
Employ NLW munition	Weapon, Non-lethal	Non-lethal weapon
Employ warhead munition	Weapon, Warhead	Warhead
Gather MET data	Environmental Sensors, MET	Device for collecting meteorological data

TABLE 4-4. ALLOCATION OF SUB-FUNCTIONS TO MODULES (CONTINUED)

SUB-FUNCTION	MODULE	DESCRIPTION
Gather ocean data	Environmental Sensors, OHB	Device for collecting oceanographic, hydrographic, and bathymetric data
Gather samples	Sample Gatherer-Processor	Device for collecting and analyzing samples (air, water, ground) for analysis, e.g., to detect chemical, bacteriological or radiation contamination
Grasp and load air objects	Manipulator, UAV	Object manipulator for unmanned air vehicles
Grasp and load ground objects	Manipulator, UGV	Object manipulator for unmanned ground vehicles
Grasp and load surface objects	Manipulator, USV	Object manipulator for unmanned surface vehicles
Grasp and load undersea objects	Manipulator, UUV	Object manipulator for unmanned underwater vehicles
Install cable	Cable Layer	Device for deploying communications cable
Interface Jammer to Comms	Interface, Jammer to Comms	Device for interfacing the electromagnetic signal jammer to the "hotel" communications module
Interface Nav to Comms	Interface, Nav to Comms	Device for interfacing the navigation data source to the "hotel" communications module
Interface Signal Interceptor to Comms	Interface, Intercept to Comms	Device for interfacing the signal interceptor to the "hotel" communications module
Process samples	Sample Gatherer-Processor	Device for collecting and analyzing samples (air, water, ground) for analysis, e.g., to detect chemical, bacteriological or radiation contamination
Process signal to determine WARM	WARM Monitor	Device for monitoring WARM signals
Recon,Targeting, acoustic	Target-Object R-T, Acoustic, Bottom	Device for conducting R-T in the water volume using acoustic signals
	Target-Object R-T, Acoustic, Volume	Device for conducting R-T on the sea bottom using acoustic signals
Recon,Targeting, air and surface	Target-Object R-T, RF-EO-IR-mmW, Surface	Device for conducting R-T on the sea surface using electromagnetic signals
	Target-Object R-T, RF-EO-IR-mmW, Ballistic Missiles	Device for conducting R-T against ballistic missiles using electromagnetic signals
	Target-Object R-T, RF-EO-IR-mmW, Ground	Device for conducting R-T over land using electromagnetic signals
	Target-Object R-T, RF-EO-IR-mmW, Air	Device for conducting R-T in the air using electro-magnetic signals
Recon,Targeting, magnetic	Target-Object R-T, Magnetic	Device for conducting R-T at sea using magnetic signals
Relay Translator	Relay Translator	Device for translating signals types as part of a signal relay function

TABLE 4-4. ALLOCATION OF SUB-FUNCTIONS TO MODULES (CONTINUED)

SUB-FUNCTION	MODULE	DESCRIPTION
Sense fields	Signature Monitor	Device that senses acoustic, magnetic, or pressure signals emanating from a platform
Sense radiation	Radiation Sensor	Radiation sensor
Store information	Data Storage	Digital data storage device
Surveillance, acoustic	Target-Object Surveillance, Acoustic, Volume	Device for conducting surveillance and warning in the water volume with acoustic signals
Surveillance, RF-EO-IR-mmW	Target-Object Surveillance, RF-EO-IR-mmW, BMs	Device for conducting surveillance and warning against ballistic missiles using electromagnetic signals
	Target-Object Surveillance, RF-EO-IR-mmW, Surface	Device for conducting surveillance and warning on the sea surface using electromagnetic signals
	Target-Object Surveillance, RF-EO-IR-mmW, Ground	Device for conducting surveillance and warning over land using electromagnetic signals
	Target-Object Surveillance, RF-EO-IR-mmW, Air	Device for conducting surveillance and warning in the air using electromagnetic signals
Terminal guidance, acoustic	Weapon Guidance, Acoustic	Device to guide a weapon to its target using acoustic signals
Terminal guidance, magnetic	Weapon Guidance, Magnetic	Device to guide a weapon to its target using magnetic signals
Terminal guidance, RF-EO-IR-mmW	Weapon Guidance, RF-EO-IR-mmW	Device to guide a weapon to its target using electro-magnetic signals
Track-update own position, low accuracy	Navigation, Low Accuracy	Device that can provide low accuracy (tactical grade) navigation information to other units
Track-update own position, med accuracy	Navigation, Med Accuracy	Device that can provide medium accuracy (inertial grade) navigation information to other units

TABLE 4-5. MISSION PACKAGES

PACKAGE NAME	DESCRIPTION	MODULES
Acquire Enviro Data, MET	Meteorological data collection package	Data Storage
		Env Sensors, Meteorological
Acquire Enviro Data, OHB	Oceanographic, hydrographic, and bathymetric data collection package	Data Storage
		Env Sensors, Oceano-Hydro-Bathy
Acquire Signals, C^3 or Weapon	Enemy signals interception package (communications, weapons, surveillance, etc.)	Interface, Intercept to Comms
		Data Storage
Acquire Signals, WARM	WARM signals interception package	WARM Monitor
		Interface, Intercept to Comms
		Data Storage
BDA, Ground	Sensor package for performing battle damage assessment over land	Battle Damage Assessment, RF-EO-IR-mmW
		Data Storage

TABLE 4-5. MISSION PACKAGES (CONTINUED)

PACKAGE NAME	DESCRIPTION	MODULES
BDA, Sea Surface	Sensor package for performing battle damage assessment over the sea surface	Battle Damage Assessment, RF-EO-IR-mmW
		Data Storage
BDA, UW, Bottom	Sensor package for performing battle damage assessment over the sea bottom	Battle Damage Assessment, Acoustic
		Data Storage
Cable Installer	Undersea or ground communication cable installation package	Cable Layer
		Nav, Med Accuracy
CBR Monitor	Chemical, bacteriological, and radiation monitoring package	Radiation Sensor
		Sample Gatherer-Processor
		Data Storage
Comms Relay	Communication relay package	Relay Translator
		Data Storage
Jamming-Deception, Air and Surface	Electromagnetic signal jamming and deception package	Interface, Deception to Comms
		Interface, Jammer to Comms
Jamming-Deception, Mine Sweep	Influence mine sweeping package	Interface, Deception to Comms
Jamming-Deception, Underwater	Acoustic signal jamming and deception package	Interface, Deception to Comms
		Interface, Jammer to Comms
Load and Delivery, Air	Object loading and delivery package for air vehicles	Weapon Guidance, RF-EO-IR-mmW
		Manipulator, UAV
Load and Delivery, Ground	Object loading and delivery package for ground vehicles	Manipulator, UGV
		Weapon Guidance, RF-EO-IR-mmW
Load and Delivery, Sea Surface	Object loading and delivery package for sea surface vehicles	Manipulator, USV
		Weapon Guidance, RF-EO-IR-mmW
Load and Delivery, Underwater	Object loading and delivery package for underwater vehicles	Weapon Guidance, Acoustic
		Manipulator, UUV
Nav Aid, Mobile, Air and Surface	Mobile, inertial grade navigation stations package using electromagnetic signals	Nav, Med Accuracy
Nav Aid, Mobile, Underwater	Mobile, inertial grade navigation stations package using acoustic signals	Nav, Med Accuracy
Nav Aid, Stationary, Air and Surface	Stationary, tactical grade navigation stations package using electromagnetic signals	Nav, Low Accuracy
Nav Aid, Stationary, Underwater	Stationary, tactical grade navigation stations package using acoustic signals	Nav, Low Accuracy
Recon-Targeting, Air	Reconnaissance and targeting package against targets in the air using electromagnetic signals	Target-Object R-T, RF-EO-IR-mmW, Air
		Data Storage
Recon-Targeting, Ballistic Missile	Reconnaissance and targeting package against ballistic missiles using electromagnetic signals	Target-Object R-T, RF-EO-IR-mmW, BMs
		Data Storage

TABLE 4-5. MISSION PACKAGES (CONTINUED)

PACKAGE NAME	DESCRIPTION	MODULES
Recon-Targeting, Ground	Reconnaissance and targeting package against targets on the ground using electromagnetic signals	Target-Object R-T, RF-EO-IR-mmW, Ground Data Storage
Recon-Targeting, Sea Surface	Reconnaissance and targeting package against targets on the sea surface using electromagnetic signals	Target-Object R-T, RF-EO-IR-mmW, Surface Data Storage
Recon-Targeting, UW, Bottom	Reconnaissance and targeting package against targets in the water volume using acoustic signals	Target-Object R-T, Acoustic, Bottom Data Storage
Recon-Targeting, UW, Volume	Reconnaissance and targeting package against targets on the sea bottom using acoustic signals	Target-Object R-T, Acoustic, Volume Data Storage
Surveillance and Warning, Air	Surveillance and warning package against targets in the air using electromagnetic signals	Target-Object Surveillance, RF-EO-IR-mmW, Air Data Storage
Surveillance and Warning, Ballistic Missile	Surveillance and warning package against ballistic missiles using electromagnetic signals	Target-Object Surveillance, RF-EO-IR-mmW, BMs Data Storage
Surveillance and Warning, Ground	Surveillance and warning package against targets on the ground using electromagnetic signals	Target-Object Surveillance, RF-EO-IR-mmW, Ground Data Storage
Surveillance and Warning, Sea Surface	Surveillance and warning package against targets on the sea surface using electromagnetic signals	Target-Object Surveillance, RF-EO-IR-mmW, Surface Data Storage
Surveillance and Warning, UW, Volume	Surveillance and warning package against targets in the water volume using acoustic signals	Target-Object Surveillance, Acoustic, Volume Data Storage
Structure Inspection	Surveillance and warning package against targets on the sea bottom using acoustic signals	Target-Object R-T, Acoustic, Volume Signature Monitor
Weapon, Directed Energy	Directed energy weapon	Weapon Guidance, RF-EO-IR-mmW Weapon, Direct Energy
Weapon, Gun	Kinetic energy weapon	Weapon Guidance, RF-EO-IR-mmW Weapon, Gun
Weapon, Non-lethal	Non-lethal weapon	Weapon Guidance, RF-EO-IR-mmW Weapon, Non-lethal
Weapon, Warhead (acoustic guide)	Underwater missile (torpedo) guided via acoustic signals	Weapon Guidance, Acoustic Weapon, Warhead
Weapon, Warhead (magnetic guide)	Underwater missile guided via magnetic signals	Weapon Guidance, Magnetic Weapon, Warhead
Weapon, Warhead (RF guide)	Air missile guided via electromagnetic signals	Weapon Guidance, RF-EO-IR-mmW Weapon, Warhead

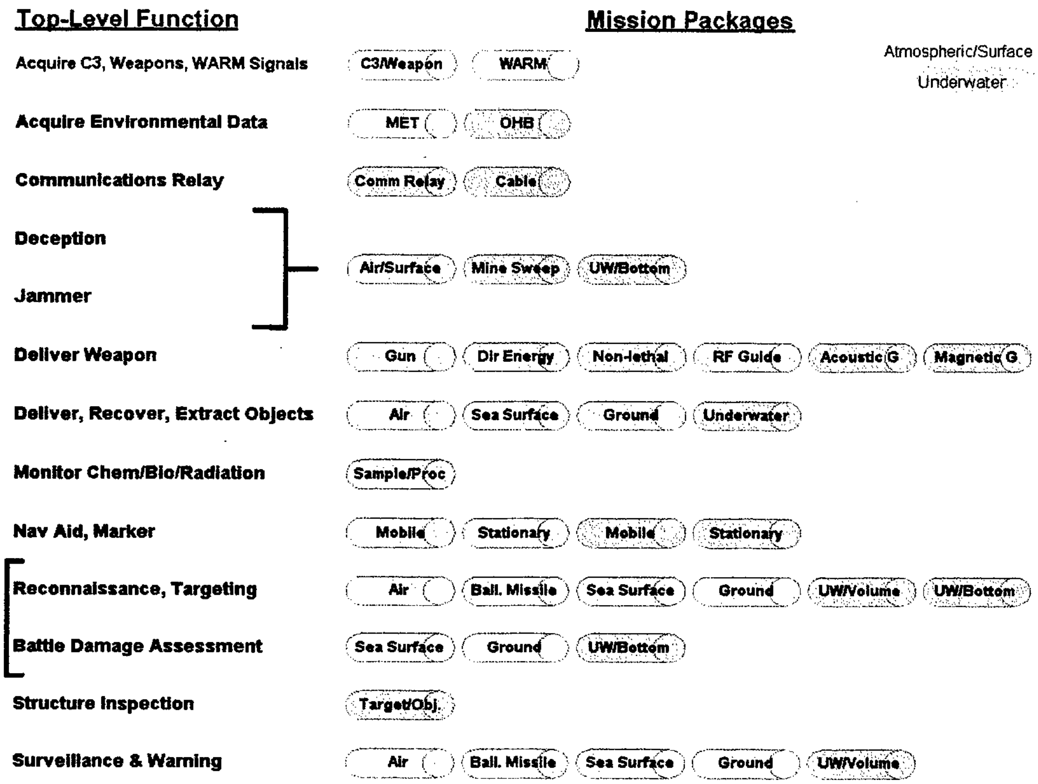


FIGURE 4-2. UNMANNED SYSTEMS MISSION PACKAGES

The concept for using these packages is illustrated in Figure 4-3. This figure shows three unmanned platform types, UUV, USV, and UAV, although it applies to UGVs as well. One or more mission packages are installed in the unmanned vehicle payload section according to the task to be performed. For example, a UUV is tasked to deploy some underwater sensors and collect environmental data. For this mission the vehicle would be configured with a "Load and Delivery, Underwater" package and an "Acquire Environmental Data (OHB)" package. For a mine reconnaissance mission, the same UUV would be configured with the OHB package plus "Recon-Targeting, UW, Volume" and "Recon-Targeting, UW, Bottom" devices to sense the mines. Similarly, a USV tasked to perform a decoy mission would be configured with "Jamming-Deception, Air and Surface" and "Jamming-Deception, Underwater" packages, while a submarine hunting task would require "Surveillance and Warning, UW, Volume" and OHB packages. The figure also shows potential payloads for a UAV to perform tasks like air target monitoring and tracking, communications relay, and battle damage assessment.

Each platform provides power to the payload and interfaces to hotel functions. Communications between the payload and the operator are handled via the vehicle's on-board communication subsystem. To reduce costs and simplify logistic support, the platforms share as many hotel components as possible. The most likely functional areas in which common components can be developed are navigation, guidance and control, and communications. Some commonality may be possible in future power systems with the introduction of fuel cell technology. Propulsion and control actuation will most likely remain platform-specific components.

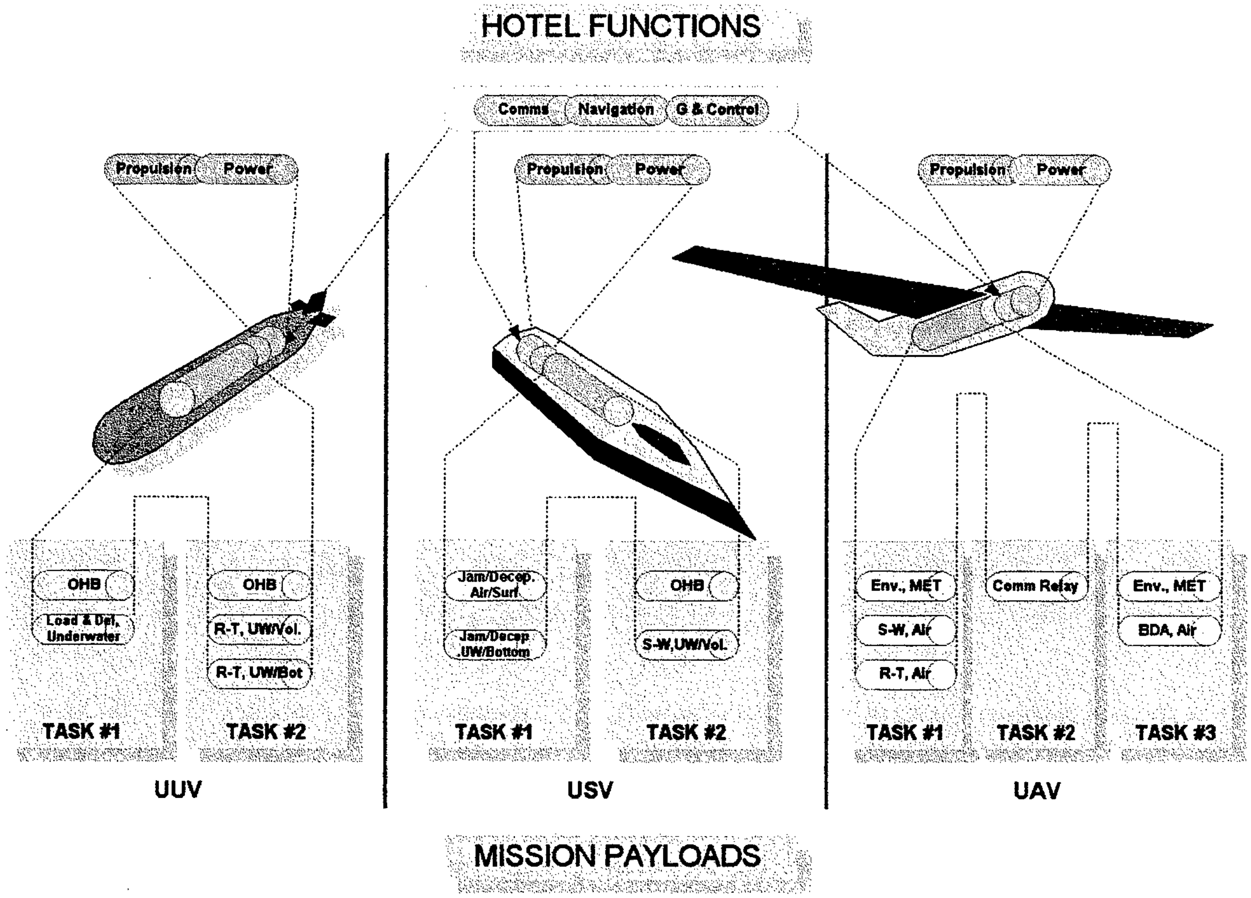


FIGURE 4-3. ILLUSTRATION OF RECONFIGURABLE UNMANNED PLATFORMS

4.3.4 Decomposition Results

As mentioned earlier, the selection of functions (and therefore, the identification of mission packages) is to some extent subjective. Therefore, it is possible that others who perform a similar decomposition analysis could end up with a few more or a few less required packages to support the original set of capabilities. Nevertheless, the main conclusion of the analysis is this: *A relatively small number of mission payloads installed on a limited number of unmanned platform types can support a very broad set of Navy operational capabilities.* Since the originating requirements include some of the most critical naval capabilities, unmanned systems developed according to the functional decomposition can contribute significantly to the most important Navy missions.

Further development of the unmanned systems concept requires establishing operational requirements for the missions to be supported. These requirements allow the derivation of critical system specifications like endurance, time to complete a mission, sensing and engagement ranges, and the numbers and types of unmanned platforms needed.

In the process of addressing operational requirements it may become evident that a single size of a given platform type is not adequate. For example, it may turn out that two or three sizes

of UAVs or USVs are necessary to support all the operational capabilities. A small number of vehicle sizes is acceptable as long as the logistic support needs between sizes are similar or common. Vehicle size is a critical characteristic because of its impact on the lift problem of how to store, transport, and sustain the unmanned platforms in the area of operations. Section 5.0 will discuss the lift concept for the proposed unmanned systems. This concept is based on using standard shipping containers for transporting and deploying the unmanned platforms. This approach limits the size of the unmanned platforms to that which can be stored in a container. Conceptually, platforms of this size can perform meaningful Navy tasks.

It should be noted that the use of reconfigurable, modular systems is already practiced in the Navy. For example, general-purpose bombs are configured into MK 62 and MK 65 Quickstrike shallow water mines by adding a target detection device. The same bombs may be converted into standoff gliding weapons by adding a wing kit. In another example, an F/A-18 aircraft can be configured with a wide variety of weapons according to mission needs. The reconfiguration is possible because the weapons comply with electrical, electronic, and mechanical interface standards that make them compatible with the aircraft's payload capabilities. The establishment and compliance with such standards makes the F/A-18 a flexible weapons platform. Similar standards are needed to limit the proliferation of unmanned platform types.

SECTION 5.0 LIFT: BRINGING THE UNMANNED SYSTEMS TO THE FIGHT

To augment the Fleet and "participate in the fight" unmanned systems must get to theater, be deployed, be tended to or not, as appropriate, and then be redeployed or recovered. Since space aboard combatants is generally limited and already either occupied by a variety of existing systems, or set aside for existing requirements, several natural questions arise. *From where should unmanned systems be deployed? From where should the unmanned systems be controlled? To where should unmanned systems be returned and serviced?*

A straightforward answer would be to do all from the combatant platform(s) closest to the "fight". This approach, while intuitive, is not the only possible one. There is a range of options to consider. Unmanned systems can be deployed from as close as the closest combatant, to as far away as CONUS. Likewise, unmanned systems may be controlled locally or remotely, or be totally autonomous. All options merit close examination. In this section we address some options for getting unmanned systems to the fight, launching, then sustaining them, and retrieving them for redeployment.

The *Super-Organic Option* is one in which an unmanned system is hosted by, deployed from, controlled from, and retrieved by the platform (combatant) that derives the principal benefit from the unmanned system. The *organic option* is one in which the unmanned system is hosted, deployed, and retrieved by a platform (combatant) that is part of a squadron or task force, but which is not necessarily the principal beneficiary. In this situation tactical command and control of the unmanned system is conducted by the combatant in most need.

An *Auxiliary-Based Option* is one in which unmanned systems are deployed from non-combatant platforms such as one might find in the strategic sea-lift program or with the maritime pre-positioned force. Another option is a *Shore-Based Option* in which the unmanned systems deploy from a close-in, or even a remote, shore-based or land-based facility.* There are likely to be a variety of basing, deployment, retrieval, and command and control options that present themselves. Which option is best depends on a number of factors, including the range of scenarios one considers, technological feasibilities, and a variety of operational concepts.

Obviously, there are many command and control relationships possible with different merits. An unmanned system can be controlled from quite far away given appropriate communication pipes. At times, it may in fact make more sense to have certain functions of the unmanned systems monitored and controlled remotely by a well-rested crew in a hospitable climate and time-zone, instead of being controlled by a weary, overextended or exhausted crew in the dead of night in a very inhospitable climate.

For the purposes of our investigation, the authors explored a variety of situations that would demand more than just one or two unmanned systems involved in executing a sustained

* As an example, Global Hawk, an unmanned aerial vehicle was reported in a recent air-force press release (http://www.af.mil/newspaper/v2_n16/v2_n16_s5.htm) to have achieved a continuous flight of 31.5-hour and will soon fly a trans-Atlantic flight to Europe from Eglin Air Force Base in Florida.

mission. Our interest was to identify a robust and scalable employment concept that would not be limited by individual combatant characteristics, and weight and cube limitations. The overriding principle guiding the exploration is the one articulated earlier: to help the human warfighter by providing labor-reducing approaches. Specifically, there is an interest in reducing the amount of low-cognitive-content (dull) labor performed by warfighters, and assisting the removal of much of the dirty and dangerous work where appropriate. Ultimately, the desired result is making combatant platforms more capable by providing more "mission capability" per person at a lower aggregate cost.

Keeping in mind all the mission and combat factors as key elements, the authors then addressed the issues of logistics, lift, and scalability up to and exceeding conditions of major contingencies. One overall conclusion that emerged is that to make a substantial difference in combat, one would have to employ more than just one or two unmanned systems. In very much the same way that one or two Tomahawks do not decide a major war, one or two unmanned systems are not likely to decide major naval engagements. The inherent need for combat-force scalability motivates exploring logistics considerations in earnest. With this perspective in mind, the investigation turned to exploring the auxiliary-based option, where unmanned systems are deployed from non-combatant platforms. This by no means suggests that this is the only approach, but it is one that merits scrutiny.

With the auxiliary-based option for lift as a basis for bringing an unmanned system to the battle, one more step remains to complete the picture; namely, recognizing that almost all the auxiliary logistics ships, railways, trucking, and port cargo movement handling systems are configured to handle standard containers (the ISO containers discussed in Section 2.0). The standardization discussion of Section 2.0 highlighted the convergence of the entire U.S. transportation and freight moving system to true intermodality and standardization of container sizes and fittings to 8-ft wide and 8-ft high containers with standard lengths of 20 and 40 ft.* These very specific parameters can now become the underlying dimensional design standards for all types of unmanned systems. These aspects will be discussed in more detail in the remainder of this section.

Thus key flexible scalable deployment and lift consideration are:

- Use of auxiliary ships for carrying and deploying unmanned systems
- Adoption of the ISO standard 20- and 40-ft containers as the limiting dimensional design basis for all new unmanned systems.

* The TEU is a standard container measure; it stands for twenty-foot equivalent unit. The actual dimensions for the standard 20 ft container are 20 ft x 8 ft x 8 ft 6 in (length x width x height) external, 19 ft 4-1/16 in x 7 ft 8-1/2 in x 7 ft 9-7/8 in internal (height to load line), and 59,523 lb gross weight, 4,739 lb tare, 54,783 lb payload, 1,179 cubic ft capacity to load line. The 40 ft container is a 2 TEU equivalent, with 65,497 lb payload capacity, and 2,393 cubic ft internal volume capacity. Data is per information on Maersk-Sealand's web site http://www.maersksealand.com/.

5.1 RATIONALE FOR USE OF CONTAINERS

That containers and containerization are important ingredients to success of any sustained military operation has been recognized in Joint Publications.** Joint Pub 4-01.5 states "Containerization is the term used to describe the transportation of goods in standardized boxes or containers (usually 8-ft wide by 8-ft high by either 20- or 40-ft long) so that shipments may be unitized and thereby reduce handling costs and increase cargo security during movement (e.g., from a self-sustaining container ship or by a auxiliary crane ship)." Later, the same document states "When operationally feasible and the tactical situation allows, *container operations are the preferred method for handling cargo through a water terminal*, especially when large volumes are required for sustainment operations." (the italics are in the original document).

In addition to auxiliary ships that are part and parcel of the U.S. Navy, use of standard containers allows straightforward integration of a host of other resources such as the U.S. Transportation Command - controlled fleet; i.e., the fast sealift ships, the Ready Reserve Force, large, medium speed roll-on/roll-off vessels, and commercial vessels as needed. Likewise, the maritime pre-positioned force (MPF) has a potential role to play here. This is especially important as discussion of next generation MPF is just now getting underway, and a major conceptual move towards sea-basing is taking place. The importance of the ability to handle standard containers is emphasized by having an entire class of ships, the auxiliary crane ships, which provide heavy-lift cranes and capability to load and unload. It is also interesting to note here that three different types of Navy combat logistics units have the ability and experience to handle containers. These are cargo handling battalions, freight terminal units, and Navy Overseas Air Cargo Terminal. Joint Pub No. 4-01.7 also describes quite a variety of standard container-handling equipment.

An ideal stowing and deployment environment would be available if a recent Naval Studies Board finding is adopted. In the 1997 report *Technology for the United States Navy and Marine Corps, 2000-2035; Becoming a 21st-Century Force*,[32] the panel on logistics considered and advised construction of a:

> "Sea-based support ship … having the principal features desired for sea-basing, **that is, automated container handling, stowage, and retrieval;** workspace for breaking out and repackaging; hangar space for maintaining aircraft or other equipment; heavy-lift helicopters; well-deck for lighters or air-cushion vehicles; and an unobstructed 900-foot flight deck. Also included in the concept by its originator was

** To get a sense of the recognition given to standard containers, note the number of Joint Publications that make direct reference to their use in Joint operations, for example: Joint Pub No. 4-01.7, Joint Tactics, Techniques and Procedures for Use of Intermodal Containers in Joint Operations, 1997, Joint Publication 4-01.5, Joint Tactics, Techniques and Procedures for Water Terminal Operations, 1996, and Joint Publication 4-01.2, Joint Tactics, Techniques and Procedures for Sealift Support to Joint Operations, 1996. Joint Pub No. 4-01.7 specifically states "The majority of containers conform to ISO specifications. The inventory of US-owned commercial containers continues to grow dramatically. In the continuing necessity to containerize increasing volume of goods, customers have sought containers of increased height, length, and width. Despite this trend in volumetric growth, the majority of the US-owned standard dry cargo container fleet remains as 20- and 40-foot units.

a new-design, fixed-wing, container-carrying aircraft. The sea-based support ship would be a large ship, designed for storing and distributing supplies in large quantities. Additionally, it would contain the necessary communications and computer capacity to provide a logistic operations center."

On the commercial side, shippers are using more and more container ships, making them both more available, as well as having ships that can carry a large number of containers at one time. The largest container ships at this time are owned by Maersk-SeaLand and can transport up to 6,600 TEUs at a time, which is quite an impressive capability. Ships with higher container carrying capabilities are already on the drawing boards.

With a view to the importance of containers and to the potential for deployment of unmanned systems from auxiliaries and the Combat Logistics Force, ships entering the Service Life Extension Program should apply some of these considerations for existing combatants (e.g. LSDs), and modify them to act as mother ships for the container-based unmanned forces.

It is interesting to note that dimensional standardization has been an item of continuing interest to the Marine Corps and, in fact, recent budgetary documents[*] point to a sustained effort for transitioning to standardized containerization. The theme of dimensional standardization and modular suiting has been discussed in studies oriented at a future Marine Corps employing "Operational Maneuver from the Sea " and "Ship to Objective Maneuver". In a very detailed report[**], the analyst suggests an operational sea-base (SBx) located up to 200 miles offshore, with an ability to support forces as far in as 100 miles inland. The report recommends a SBx and a ship-to-shore-to-ship transfer vehicle (designated Vx) that has an ability to transfer "standard containers, equipment and vehicles at weights up to 50,000 lb, and up to 12 ft in width, 12 ft in height, and 40 ft in length". The SBx would require about 5500 TEU slots for 60 day operations. (This could be accomplished by a number of medium sized MPF ships or with fewer, but larger ships). There are a number of other detailed characterizations, but the key measure in the report is the number of TEU slots needed and available for different scenarios.

5.2 ADDITIONAL CONSIDERATIONS

An interesting question arises: if standardized containers are so prevalent and unmanned systems are so promising, has anything been done to bring the two together? Initially, it appeared that this was not the case. Upon closer examination, some interesting data began to emerge. It appears that as early as 1990, a large-diameter UUV was housed and deployed from a container in Dabob Bay, Washington by Draper Laboratories. In the last few months, several

[*] Procurement, Marine Corps (1109) / Engineer and Other Equipment (6) / 073 1999 Display shows budgets ranging from $6.2 M/ year to $11.5M on a continuing basis. The supporting statement states: "The Container Family will provide the Fleet Marine Force with a fully intermodal transport capability emphasizing dimensional standardization and International Organization for Standardization compatibility. Containers will replace locally assembled prefabricated wooden mount out boxes and flat and box pallets. The containers will be used to support storage and movement of organizational property and consumable supplies, provide field, garrison and shipboard warehousing, and facilitate ship- to- shore movement."

[**] Marine Corps Logistics 2010, Agrilog Inc. Report, 1 December 1995, prepared for the Naval Facilities Engineering Center, Contract N47408-93-C-7340. It is interesting to note that this document was used as a basis for the Naval Studies Board examining the Logistics area discussed earlier.

publications reported and actually printed photographs of a commercial UUV deployed from a container. This vehicle is the Hugin 3000 Autonomous UUV and is shown in Figure 3-8 along with the Boeing Unmanned Combat Aerial Vehicle stowed in a storage/transport container. Apparently, the idea of unmanned systems stowed, transported, and sometimes directly deployed from a container makes a great deal of sense and is already being addressed in the commercial marketplace. However, there are a number of considerations not being addressed.

Except for CSS's effort reported here, we have not found other organizations pursuing a systematic effort to address deployment and retrieval of a large number of unmanned systems in a generic, scalable, coherent approach. The varieties of platform designs in existence today are all unique, making each unmanned system's deployment/launch and recovery unique and expensive in design and production. Adoption of the approach suggested here would go a long way towards improving cost and fleet introduction profiles of next-generation unmanned systems.

In line with our overall approach to automation and reducing manual labor, we strongly advocate development of totally unmanned mechanisms to launch and recover unmanned systems. This entails investment in technologies internal to containers that would support total automation of monitoring and packaging, robotics for automated launch and recovery operations, and automation for post-recovery maintenance and servicing.

If we accept some prevalent notions for success in combat such as the ability to surprise the enemy, outnumbering the enemy during combat, and maneuverability (in the Boydian sense of being able to switch rapidly between different modes of engagement), unmanned systems deployed from containers clearly enhance and augment the naval forces. In designing deployment of unmanned systems from containers, one must keep in mind the requirement to generate high sortie rates per day and the ability to sustain the unmanned systems employed. Consideration of sorties, mission durations, and intrinsic capabilities of unmanned systems also suggest immediate attention to opportunities to have unmanned systems function as the sustainment and resupply platforms for unmanned systems on duty stations.

Associated with the general "Lift" discussion, there is the opportunity to examine in more detail what Agrilog called a "ship-to-shore-to-ship transfer vehicle", which is intrinsically a logistics transfer vehicle. In a recent conference, Bell Helicopter-Textron introduced the VTOL Heavy Cargo TiltRotor concept (a quad-rotor and safer modification of MV-22) that would be able to deliver one 40-ft ISO container or two 20-ft ISO containers).[34] Other transfer vehicles that could be appropriately configured are the Landing Craft, Air Cushion Vehicle (LCAC) and the new catamaran concept under experiment at the Naval War College. Any one or all of these concepts may be valuable in bringing preloaded containers closer to the combat zone, without being in the combat zone, and launching the unmanned systems.

Figure 5-1 shows a notional stacking of 40-ft containers onboard a hypothetical generic cargo ship. With a common, standard, automated load and roll pallet assembly internal to the containers, one might launch USVs, UUVs, and UAVs with rocket-assisted takeoff directly from their ISO containers, as illustrated. Figure 5-2 shows a zoomed-in notional view of the USV launch for better clarity. Figure 5-3 offers a notional illustration of potential ISO container

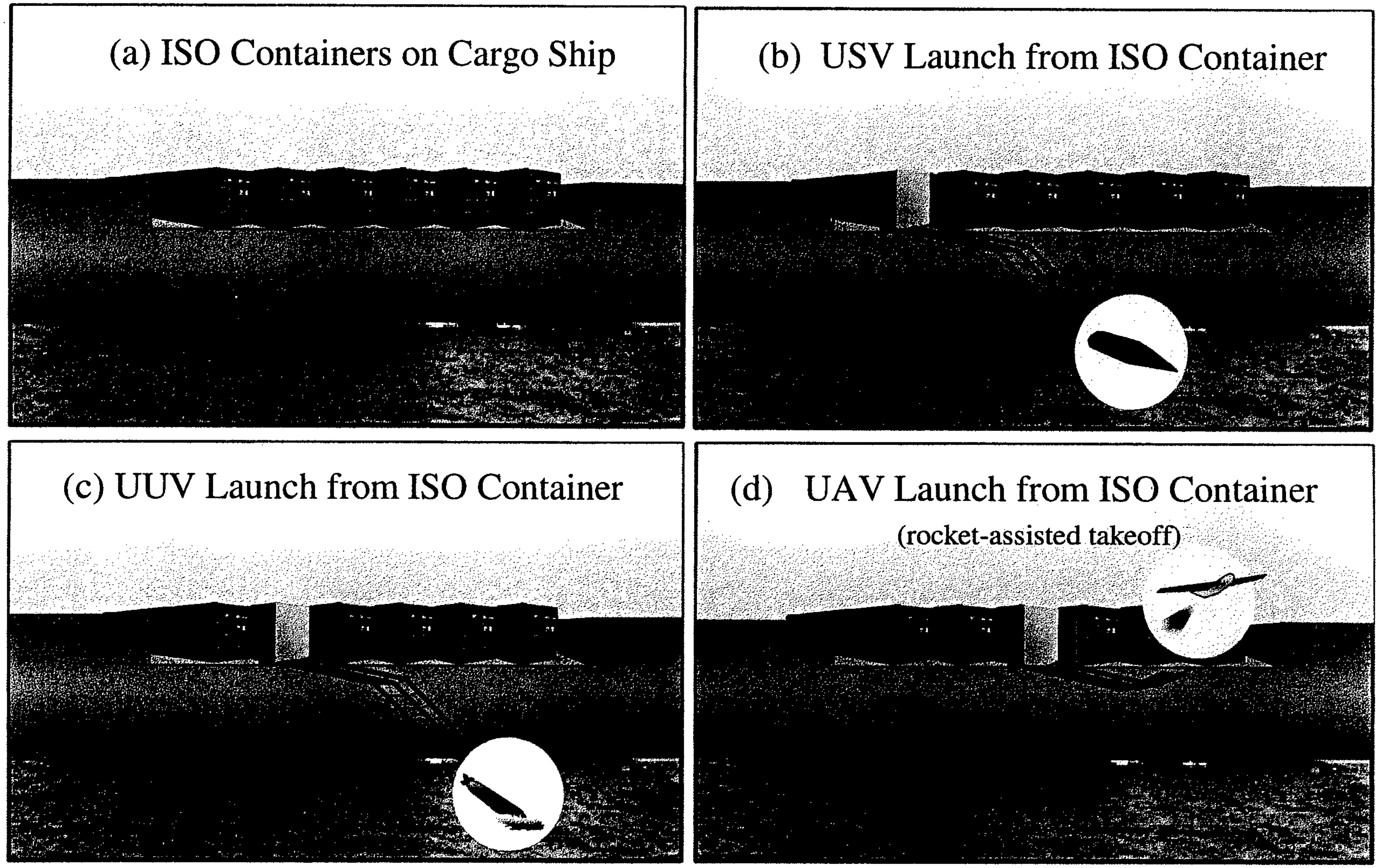


FIGURE 5-1. NOTIONAL DEPICTION OF UNMANNED SYSTEMS LAUNCH SEQUENCE FROM ISO CONTAINERS ONBOARD A CARGO SHIP

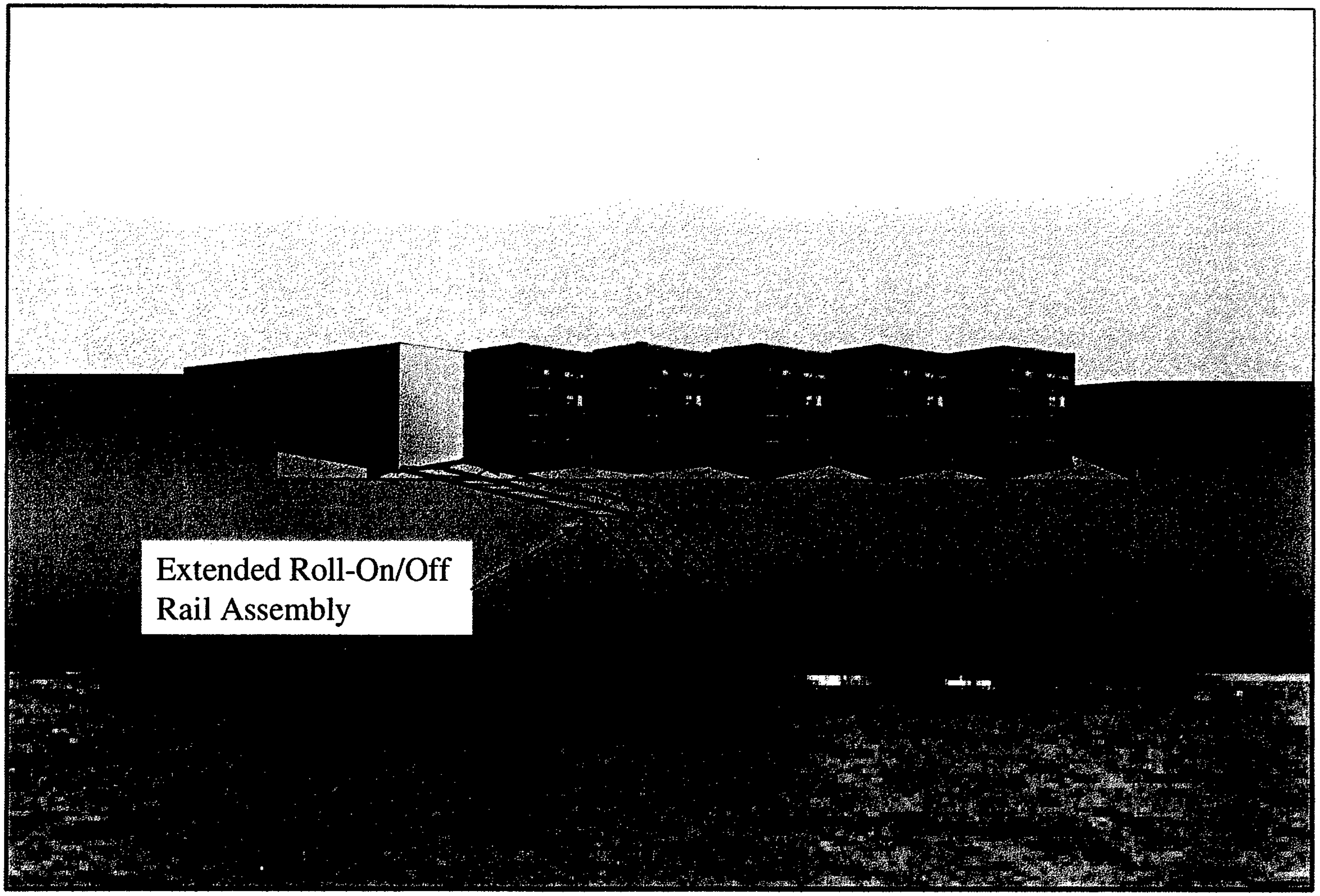
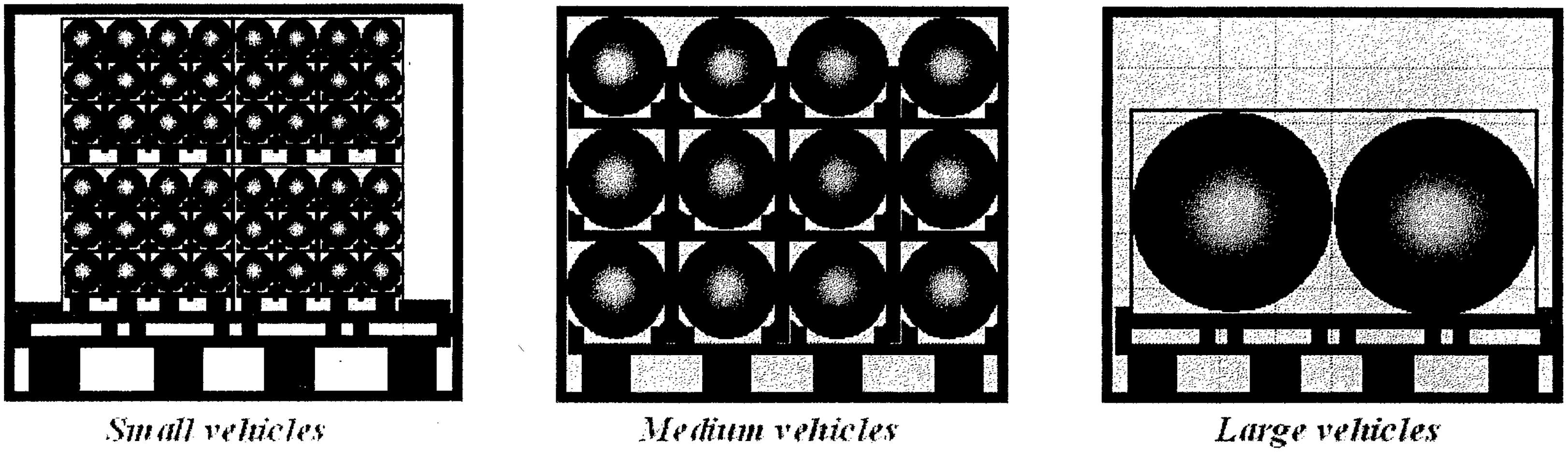


FIGURE 5-2. CLOSE-UP VIEW, NOTIONAL DEPICTION OF USV LAUNCH FROM ISO CONTAINER ONBOARD A CARGO SHIP



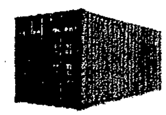
Unmanned System Loadout		20' x 8'6" x 8'0" Standard ISO (payload =47,800 lbs.) 	40' x 8'6" x 8'0" Standard ISO (payload 58,800 lbs.) 
small	8" Dia x 8' Length	96 Unmanned Vehicles	192 Unmanned Vehicles
	8" Dia x 16' Length	48 Unmanned Vehicles	96 Unmanned Vehicles
medium	21" Dia x 8' Length	24 Unmanned Vehicles	48 Unmanned Vehicles
	21" Dia x 16' Length	12 Unmanned Vehicles	24 Unmanned Vehicles
large	42" Dia x 8' Length	4 Unmanned Vehicles	8 Unmanned Vehicles
	42" Dia x 16' Length	2 Unmanned Vehicles	4 Unmanned Vehicles

FIGURE 5-3. NOTIONAL DEPICTION OF POSSIBLE ISO CONTAINER LOADOUTS OF STANDARD-SIZED UNMANNED SYSTEMS

loadout configurations for unmanned systems in several standard sizes, and rough estimates of the number of vehicles that might be loaded per container. The figure also conveys the notion of standardized, scaleable launch and recovery components that allow "plug and play" insertion of different loads in any standard container. Note that the unmanned systems in any of these configurations could be mobile vehicles or stationary nodes. These configurations are just an illustrative example. Coastal Systems Station plans to develop engineering designs to support these concepts.

To summarize, there is a natural synergy between standard ISO containers and unmanned systems. Extending the employment of containers for stowing and deploying unmanned systems is an attractive option. Specifically:

- Using ISO containers means that the unmanned assets can be carried in combat logistics force and commercial ships, thus reducing the impact on the combatants
- Joint Doctrine and service documents supporting the use of containers are in place
- Infrastructure for container management (port facilities, military airlift) is in place
- Current cargo ship capabilities are attractive (there are many large ships capable of carrying thousands of containers)
- Future ship capabilities (small, fast-moving ships; automated container handling) can be explored in terms of further enhancing unmanned systems-based Naval force readiness augmentation
- Service Life Extension Programs provide a quick entry mechanism for adopting and enhancing container-based unmanned systems
- Use of ISO containers provides a rational approach to setting dimensional goals for design and construction of unmanned systems
- The Naval Studies Board has already identified merit in a sea-based approach that would provide the staging capabilities for employing unmanned systems in a meaningful way

With these conceptual tools in hand, the way is cleared for warfighting that allows total augmentation "from factory to fight" with minimal manual intervention, and on the factories' logistics terms.

SECTION 6.0 OBSERVATIONS AND CONCLUSIONS

6.1 GENERAL OBSERVATIONS AND CONCLUSIONS

Development of unmanned systems in DOD has proceeded predominantly from the "bottom up", with unique designs for specific missions and concentration on performance. Although some moves in the direction of standardization and modularity are now occurring, and master plans and coordinating program offices are established for all but USVs, the emergent systems approaches are largely for independent non-interacting unmanned systems and tend to remain segregated into specific platform "stove-pipes".

A master plan for USVs and a corresponding projects office should be established. This affords an opportunity to "do USVs right" from the start, implementing a systems design approach for a family of vehicles that incorporates principles of standardization and modularity, not only focused on USVs themselves but across all types of unmanned systems.

Additionally, a mechanism should be established to coordinate and integrate the future directions of all unmanned systems master plans, orienting new pre-planned product improvement (P^3I) and new vehicle concepts to start systematically incorporating standard and modular designs that will achieve the highest degree of interoperability in the most affordable and efficient manner.

6.2 STANDARDIZATION AND MODULARITY

Standardization and modularity will have to be applied broadly across all unmanned systems if they are to be affordable in very large numbers. Large numbers of unmanned systems will be required to augment naval forces across the full mission spectrum.

A key finding of this report is that, from a functional perspective, a limited number of general modules can be used to support a broad range of naval missions. It is important to start at this level and apply modularity across unmanned systems from the top-down. Engineering constraints and physics will impose limits on what can be accomplished, but should not drive the overall systems engineering approach. They should be applied within the context of the overall systems approach.

6.3 LIFT AND SUSTAINMENT

Lift (how unmanned systems are brought into theater) and how unmanned systems are deployed and sustained present the most significant challenges and will be big drivers in how future unmanned systems evolve to fit within warfighting doctrine. Almost every significant change in the Navy has resulted in some modification to a ship or ship class, so it is important to address now how future ships will be changed to accommodate unmanned systems.

There are a number of directions to take including new military sealift vessels, new combatant designs, and employment of commercial vessels. The key point is that application of ISO containers in several standard sizes, combined with standard launch and recovery systems that can be employed either "out of container" or organically onboard combatants, will afford the flexibility and economies of scale required for affordable acquisition and realistically achievable deployment. For example, a series of standard 21-in vehicles (UUVs and USVs and perhaps UAVs and UGVs) may all fit within a dimensional footprint to support launch and recovery from submarine torpedo tubes, or directly from ISO container "cells" off the side of a ship, or even from a novel new subsurface launch and recovery tube system integrated internally into a new surface combatant design. The significant point is the design commonality and operational flexibility afforded by such a standard family of unmanned systems.

6.4 OPERATION AND CONTROL

Deployment of very large numbers of unmanned systems in warfighting scenarios will also require dramatic changes in operation and control concepts. Today we are already thinking in terms of controlling multiple vehicles of one type (e.g. three or six UAVs) from a common control station. However, with large numbers of all types of unmanned systems, the general control strategy will have to take on an entirely new dimension wherein the theater commanders and on-scene combatant personnel become the "users" of the products and services provided by the unmanned systems, without the need to worry about the operation and control of the specific unmanned systems themselves. An illustrative example is the delivery of imagery and other intelligence products produced by national assets in real-time for consumption by theater commanders. The theater commander does not have to worry about the operation or control of the national assets themselves since he only requests and receives a product or service. The deployment, operation, and control of the national assets themselves may actually involve a broad spectrum of personnel distributed all over the globe.

6.5 IMPLICATIONS

DOD is currently investing over $600M per year on unmanned aerial vehicles, and probably upwards of $1B per year when one factors in support and training. Meanwhile, as the roles and significance of unmanned undersea, surface, and ground vehicles continue to grow to similar levels, it is reasonable to expect that the total U.S. defense budget outlay for unmanned systems will grow as well. National investment of this magnitude, with the concomitant reliance on unmanned systems to support our troops, predicates that an orderly and systematic engineering approach be instituted to mature these technologies for the significant and crucial role that awaits them in future combat.

The underlying conclusion of this report is based on the systems engineering methodology, the close examination of required capabilities statements, and the functional mission decomposition with attendant module allocations. The conclusion is that Naval forces stand to dramatically benefit from adoption of a comprehensive modular, standardized unmanned systems design, development, and deployment framework.

Coastal Systems Station believes strongly in the unmanned systems vision and concept outlined in this technical report. Consequently, Coastal Systems Station plans to undertake the development of a set of overarching systems engineering design principles for unmanned systems that can be applied in a prudent and measured manner, to future P^3I programs and the development of future unmanned systems concepts. Our ongoing work in Mine Countermeasures already spans the full spectrum of unmanned systems from UAV payloads (COBRA), to highly advanced autonomous UUVs (SAHRV, Battle Space Preparation UUV, etc.), to sophisticated state-of-the-art USVs (RMS), and finally even to highly autonomous UGVs operating in a very demanding surf zone environment (crawlers). This experience across the full spectrum of unmanned systems has led us to develop this concept and drives us to advocate its broad acceptance and implementation within the Navy and potentially, within DOD.

SECTION 7.0 REFERENCES

1. Fallows, James, *National Defense*, Random House, New York, NY, 1981.

2. U.S. Navy Active Ship Force Levels, 1917-1998, Naval Historical Center, <http://history.navy.mil/branches/org9-4.htm>.

3. Cohen, William S., Annual Report to the President and Congress, <http://www.dtic.mil/execsec/adr2000/navy.html>, Secretary of Defense, 2000.

4. SAF/PA 96-1204: UAV - Technologies and Combat Operations, <http://www.au.af.mil/au/awc/awcgate/sab-uav/uavstud.htm>.

5. New World Vistas: Air and Space Power for the 21st Century, Summary Volume, <http://www.au.af.mil/au/awc/awcgate/vistas/vistas.htm>.

6. Acceleration and Vibration, United States Naval Flight Surgeon's Manual, The Bureau of Medicine and Surgery, Department of the Navy, Third Edition, Chapter 2, 1991.

7. Clausewitz, Carl Von. On War. Translated and edited by Michael Howard and Peter Paret, Princeton University Press, Princeton, NJ, 1976.

8. Spence, Floyd D., Chairman, House Armed Services Committee, PRESS RELEASE, November 18, 1999.

9. Air-Log, <http://www.utdallas.edu/library/special/aviation/airlog.html>, January 2001.

10. Wright, T. P., "Factors Affecting the Cost of Airplane," Journal of the Aeronautical Science, February 1936.

11. Using Improvement Curves, Contract Pricing Reference Guides, Volume 2 - Quantitative Techniques for Contract Pricing, Chapter 7, <http://www.acq.osd.mil/dp/cpf/pgv1_0/pgv2/pgv2c7.html>, June 13, 2000.

12. Stewart, Rodney D.; Wyskida, Richard M.; and Johannes, James D., Cost Estimator's Reference Manual, Second Edition, John Wiley & Sons, Inc., New York, NY, 1995.

13. The Evolution of the Revolution in Containers, <http://www.maersksealand.com/maersksealand/evolution.htm>.

14. Rosenstein, Mark, The Rise of Maritime Containerization in the Port of Oakland 1950 to 1970, M.A. Thesis, New York University, September 11, 2000.

15. O'Grady, Peter, The Age of Modularity: Using the New World of Modular Products to Revolutionize Your Corporation, Adam and Steele, Iowa, 1999.

16. Baldwin, Carliss Y., and Clark, Kim B., Design Rules: The Power of Modularity, Volume 1, MIT Press, Cambridge, MA, 2000.

17. Trading Analysis of October 27 and 28, 1997: A Report by the Division of Market Regulation U.S. Securities and Exchange Commission, <http://www.sec.gov/news/studies/tradrep.htm>, September 1998.

18. 1997-1998 International Guide to Unmanned Vehicles, AW&ST and AUVSI, McGraw-Hill, 1997.

19. Unmanned Aerial Vehicles: DOD's Demonstration Approach Has Improved Project Outcomes, Letter Report, GAO/NSIAD-99-33, 08/30/1999, <http://www.fas.org/irp/gao/nsiad-99-033.htm>.

20. A Short History of Torpedoes (1866 to 1944), E.M. Cumming, <http://www.weymouthdiving.co.uk/torphist.htm>.

21. The Navy Unmanned Undersea Vehicle (UUV) Master Plan, PEO (USW), PMS403, April 20, 2000.

22. New MCM Technology Demonstrated in Naval Exercise, Office of Naval Research, August 23, 2000, <http://www.onr.navy.mil/onr/newsrel/nr000823.htm>

23. Wernli, R. L., "AUV Commercialization – Who's Leading the Pack?" MTS /IEEE OCEANS 2000, Providence, RI, September 11-14, 2000.

24. LeVan, Lt. Col R., "Joint Unmanned Ground Vehicles," Army AL&T, March-April 2001.

25. FY2000 Joint Robotics Program Master Plan, DOD Joint Robotics Program.

26. UAV Control System Prepares for Flight Demonstration, News Release, PEO (CU/UAV), October 30, 1998.

27. Peterson, R., "Unmanned Vehicles and the Tactical Control System for the DD 21," NSWC-DD Technical Digest, 1999.

28. Iannotta, B., "UCAVs Prepare for Battle," Aerospace America, March 2001.

29. *Defense Systems Management College Systems Engineering Management Guide*, Second Edition, Superintendent of Documents, U. S. Government Printing Office, Washington, DC, 1990.

30. IEEE Trial-Use Standard for Application and Management of the Systems Engineering Process, IEEE Std 1220-1994, Institute of Electrical and Electronics Engineers, February 1995.

31. EIA Interim Standard for Systems Engineering, EIA/IA-632, Electronics Industry Association, December 1994.

32. Technology for the United States Navy and Marine Corps, 2000-2035: Becoming a 21st-Century Force, National Research Council, Naval Studies Board, National Academy Press, Washington, D.C., 1997.

33. Cohen, William, Report on the Naval Vessel Force Structure Requirements, The Secretary of Defense, June 26, 2000.

34. Spivey, Dick, VTOL Heavy Cargo TiltRotor, Introducing: Quad TiltRotor, Fifth Annual NDIA Expeditionary Warfare Conference, Bay Point Marriott, Panama City, FL, 2000.

DISTRIBUTION

		COPIES
DOD ACTIVITIES (CONUS)		
DEFENSE TECHNICAL INFORMATION CENTER 8725 JOHN J KINGMAN ROAD SUITE 0944 FT BELVOIR VA 22060-6218		2
INTERNAL		
CP23	TECHNICAL LIBRARY	9
A40L	(FERNANDEZ)	2
R06	(DEMARTINO)	2
R0X	(DR MORITZ)	2
R10	(DR SUMMEY)	75
R11	(RODRIGUEZ)	2
	(PORTMANN)	2